ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-10)

C. A. Rafferty

ARO, Inc.

February 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on September 19, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on November 30, 1967.

This technical report has been reviewed and is approved.

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ABSTRACT

Five nonfiring propellant pump performance tests of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The tests were accomplished during test period J4-1801-10 at pressure altitudes of approximately 100,000 ft to evaluate the effects of low fuel pump inlet pressure on pump operating characteristics (tests 10A through 10D) and to determine the effects of spinup with dry pumps on test 10E. In the first four tests, liquid nitrogen was utilized as the operating fluid in the oxidizer system for safety reasons and to prevent engine firing on any test. Thrust chamber and turbine components were thermally conditioned before each performance test.

CONTENTS

APPENDIXES

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
NPSH	Net positive suction head, ft
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine (S/N J-2052) using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The five pump performance tests reported herein were conducted during test period J4-1801-10 on September 19, 1967, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to evaluate the effects of low fuel pump inlet pressure on fuel pump performance (test 10A through 10D) and the effects of pump spinup with dry pumps on test 10E. These pump performance tests were conducted at a pressure altitude of approximately 100,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start.

Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). No engine modifications or component replacements were performed since the previous test period. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5 through 9, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.
2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.
3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.
4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.
5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.
6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel

turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the static test stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46, 000 lb of liquid hydrogen and 199, 000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperature stratification. Vent and relief valve systems are provided for both propellant tanks. Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100, 000 ft. The basic cell construction provides a 1. 5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a low pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, pneumatic regulator, and main oxidizer valve closing control line and second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the pneumatic regulator and main oxidizer valve closing control line and second-stage actuator.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, load cells, and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Pre-operational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, pneumatic regulator, main oxidizer valve closing control line, and main oxidizer valve second-stage actuator. Table III presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Five propellant pump performance tests on the J-2 rocket engine were conducted during test J4-1801-10 on September 19, 1967. These tests were in support of the S-IVB/S-V J-2 engine developmental program. Pump performance tests 10A through 10D involved start tank discharge to determine fuel pump transient operating characteristics with below minimum model specification fuel pump inlet pressures. Performance test 10E was conducted to determine the effects of dry pump spinup on fuel and oxidizer pumps. The propellant utilization valve was held in a null position for all tests. Liquid nitrogen was utilized as the operating fluid in the oxidizer system for safety reasons and to prevent engine firing on any test. Table IV presents conditioning targets for engine components and the measured test conditions at engine start. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8.

Specific test objectives and a brief summary of results for each test are presented in the following section. Start and shutdown times of selected engine valves are presented in Table V.

Test	Test Objectives	Results
10A	Determine fuel pump operating characteristics with fuel pump inlet pressure 3 psi below minimum model specifications of 28 psia.	Fuel and oxidizer pump speeds at engine cutoff were 12,260 and 3720 rpm, respectively. No fuel pump stall tendencies or serious cavitation were experienced during the test.
10B	Determine fuel pump operating characteristics with fuel pump inlet pressure 4 psi below minimum model specification and a 100°F warmer thrust chamber than test 10A.	Fuel and oxidizer pump speeds attained at engine cutoff were 12,150 and 3610 rpm, respectively. Fuel pump discharge pressure was approximately 25 psi higher than on test 10A, because of warmer thrust chamber. No fuel pump stall or serious cavitation occurred.

Test	Test Objectives	Results
10C	Determine fuel pump operating characteristics with fuel pump inlet pressure 3 psi below minimum model specification.	Fuel and oxidizer pump speeds attained at engine cutoff were 12, 210 and 3640 rpm, respectively. No fuel pump stall or serious cavitation occurred.
10D	Determine fuel pump operating characteristics with fuel pump inlet pressure 4 psi below minimum model specification and a 100°F warmer thrust chamber than test 10C.	Fuel and oxidizer pump speeds attained at engine cutoff were 12, 230 and 3670 rpm, respectively. Fuel pump discharge pressure exceeded that of test 10C by approximately 60 psi because of warmer thrust chamber. No fuel pump stall tendencies or serious cavitation occurred.
10E	Determine the effects of dry pump spinup on fuel and oxidizer pumps.	Maximum oxidizer pump speed attained was 6940 rpm. Because of loss of magnetic properties of fuel pump speed probe at dry pump conditions, no speed measurement was obtained. Post-test visual inspection revealed no apparent damage to either pump.

Propellant pump inlet and start tank conditions obtained at engine start are compared to safe start envelopes in Fig. 8. The presentation of the test results in the following sections will consist of a discussion of each engine test with pertinent comparisons. The data presented will be those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Test J4-1801-10A

This test, conducted to study start transient fuel pump performance with low fuel pump inlet pressure, was successfully accomplished after a 1.0-sec fuel lead. Engine start and shutdown transients are presented in Fig. 9. Table V presents selected engine valve operating times for engine start and shutdown. Engine ambient pressure and combustion chamber pressure during the test are presented in Fig. 10. Pressure altitude during the test was 90, 000 ft. Liquid nitrogen was used as the operating fluid in the oxidizer system during this test. Turbine components and thrust chamber pre-test thermal conditioning are presented in Fig. 11.

The fuel pump and oxidizer pump attained speeds of 12,260 and 3720 rpm, respectively (Fig. 9) at engine cutoff (t_0 + 0.592 sec). Transient fuel pump head/flow data are presented in Fig. 12 and indicate no stall tendencies occurred during this test. The critical net positive suction head (NPSH), defined as the pump net positive suction head which reduces the pump discharge head by 2 percent because of cavitation (Ref. 5), is unavailable at test operating conditions. Figure 13 presents critical NPSH calibrations supplied by the engine manufacturer and minimum values of NPSH for tests 10A through 10D. An extrapolation of the critical NPSH curve would place the minimum values of test NPSH above the critical. It is difficult, however, to design a pump inlet capable of preventing the occurrence of at least some cavitation throughout the various flow and speed conditions encountered during engine start transient (Ref. 6). This condition of temporary cavitation during engine start transient is characteristic of several successful, large liquid-propellant rocket engines and can usually be tolerated. From the above references and Fig. 13, apparently no serious cavitation was encountered.

Fuel pump discharge pressure during test 10A is shown in Fig. 9. No engine vibration (VSC) was recorded.

4.2.2 Test J4-1801-10B

This fuel pump performance test with a warmer thrust chamber than test 10A was successfully conducted following a 1.0-sec fuel lead. Engine start and shutdown transients are shown in Fig. 14. Selected engine valve operating times for engine start and shutdown are listed in Table V. Engine ambient and combustion chamber pressure are presented in Fig. 15. Pressure altitude at engine start was 108,000 ft. Turbine component and thrust chamber thermal conditioning before test 10B is presented in Fig. 16.

The fuel pump and the oxidizer pump attained speeds of 12,150 and 3610 rpm, respectively (Fig. 14) at engine cutoff (t_0 + 0.586 sec). A comparison of fuel pump discharge pressure for tests 10A and 10B is presented in Fig. 17. An increase of 25 to 30 psia in fuel pump transient discharge pressure from test 10A to 10B is attributed to the 56°F warmer average thrust chamber temperature on test 10B. Transient fuel pump head/flow data are shown in Fig. 18 and indicate no stall tendencies occurred during this test. The critical NPSH at test operating conditions is unavailable. However, extrapolation of the critical NPSH curve supplied by the engine manufacturer would place the minimum value of test NPSH above the critical (Fig. 13). Apparently, no serious cavitation was encountered. No engine vibration (VSC) was recorded during this test.

4.2.3 Test J4-1801-10C

This fuel pump performance test with low fuel pump inlet pressure was successfully conducted after a 1.0-sec fuel lead. Engine start and shutdown transients are shown in Fig. 19. Selected engine valve operating times for engine start and shutdown are listed in Table V. Engine ambient and combustion chamber pressure are presented in Fig. 20. Pressure altitude at engine start was 107,500 ft. Thermal conditioning of turbine components and thrust chamber before test 10C is shown in Fig. 21.

The fuel pump and the oxidizer pump attained speeds of 12,210 and 3640 rpm, respectively (Fig. 10) at engine cutoff (t_0 + 0.590 sec). Fuel pump discharge pressure is shown in Fig. 19.

Transient fuel pump head/flow data (Fig. 22) indicate no stall tendencies occurred during the test. The critical NPSH at test operating conditions is unavailable. However, extrapolation of the critical NPSH curve supplied by the engine manufacturer would place the minimum value of test NPSH above the critical (Fig. 13). Apparently, no serious cavitation was encountered. No engine vibration (VSC) was recorded during this test.

4.2.4 Test J4-1801-10D

This fuel pump performance test with low fuel pump inlet pressure and a warmer thrust chamber than test 10C was successfully conducted following a 1.0-sec fuel lead. Engine start and shutdown transients are shown in Fig. 23. Selected engine valve operating times for engine start and shutdown are listed in Table V. Engine ambient and combustion chamber pressure is presented in Fig. 24. Pressure altitude at engine start was 107,000 ft. Thermal conditioning of turbine components and thrust chamber before testing is presented in Fig. 25.

The fuel pump and the oxidizer pump attained speeds of 12,230 and 3670 rpm, respectively (Fig. 23) at engine cutoff (t_0 + 0.591 sec). A comparison of fuel pump discharge pressure for tests 10C and 10D (Fig. 26) indicates an increase of approximately 60 psia in transient discharge pressure for a 69°F warmer average thrust chamber temperature.

Transient fuel pump head/flow data are shown in Fig. 27, indicating no stall tendencies occurred. Critical NPSH at test operating conditions is unavailable. However, extrapolation of the critical NPSH curve supplied by the manufacturer would place the minimum value of test NPSH above the critical (Fig. 13). Apparently, no serious cavitation was encountered. No engine vibration (VSC) was recorded for this test.

4.2.5 Test J4-1301-10E

This test was conducted to determine the effects of dry pump spinup on the structural integrity of the oxidizer and fuel pumps. No propellants were present in either propellant supply lines or pumps. Selected engine valve operating times for engine start and shutdown are listed in Table V. Engine ambient pressure is presented in Fig. 28. Pressure altitude during engine start was 72, 000 ft. The facility steam ejector was not operated on this test. Pre-test turbine component and thrust chamber conditioning is presented in Fig. 29.

Fuel pump speed was not measured for this test. The fuel pump speed probe is not designed to operate above cryogenic temperatures, because above these conditions the magnetic properties of the probe will not generate a sufficient speed signal. The oxidizer pump speed attained a peak of 6940 rpm (Fig. 30). No excessive engine vibration (VSC) was recorded during this test. Post-test visual inspection revealed no apparent damage to either pump.

SECTION V
SUMMARY OF RESULTS

The results of the five Rocketdyne J-2 rocket engine pump performance tests, using liquid hydrogen and liquid nitrogen as operating fluids in the fuel and the oxidizer systems, respectively, and conducted on September 19, 1967, in Test Cell J-4, are summarized as follows:

1. Fuel pump head/flow data indicate no stall tendencies occurred with the low fuel pump inlet pressures used for these tests.
2. Apparently, no serious fuel pump cavitation was encountered on any of the four pump performance tests at lowered fuel pump inlet pressures, although no cavitation margin is available at test conditions.
3. Pump spinup without propellants in the pumps caused no visible damage to either oxidizer or fuel pump.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION

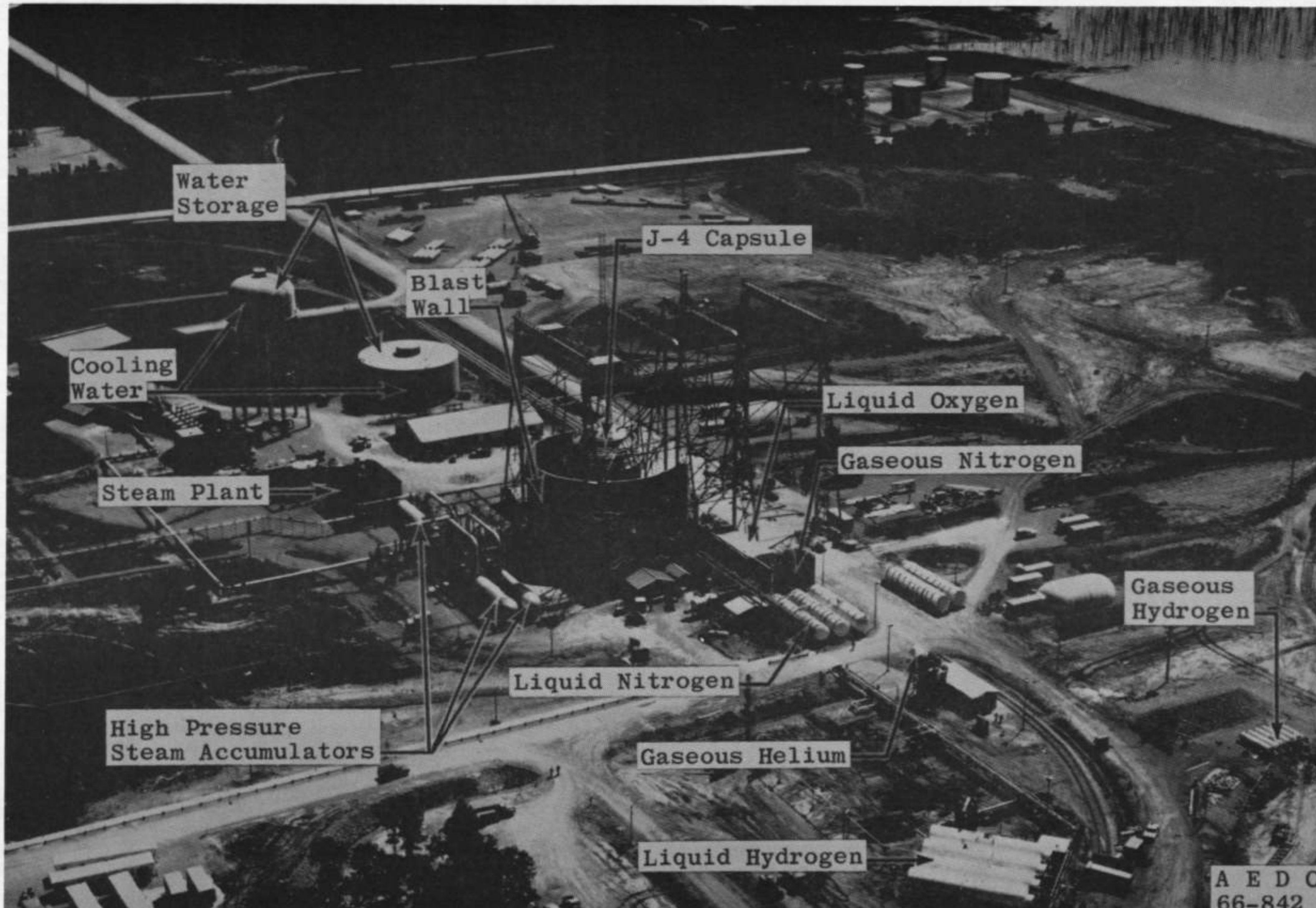


Fig. 1 Test Cell J-4 Complex

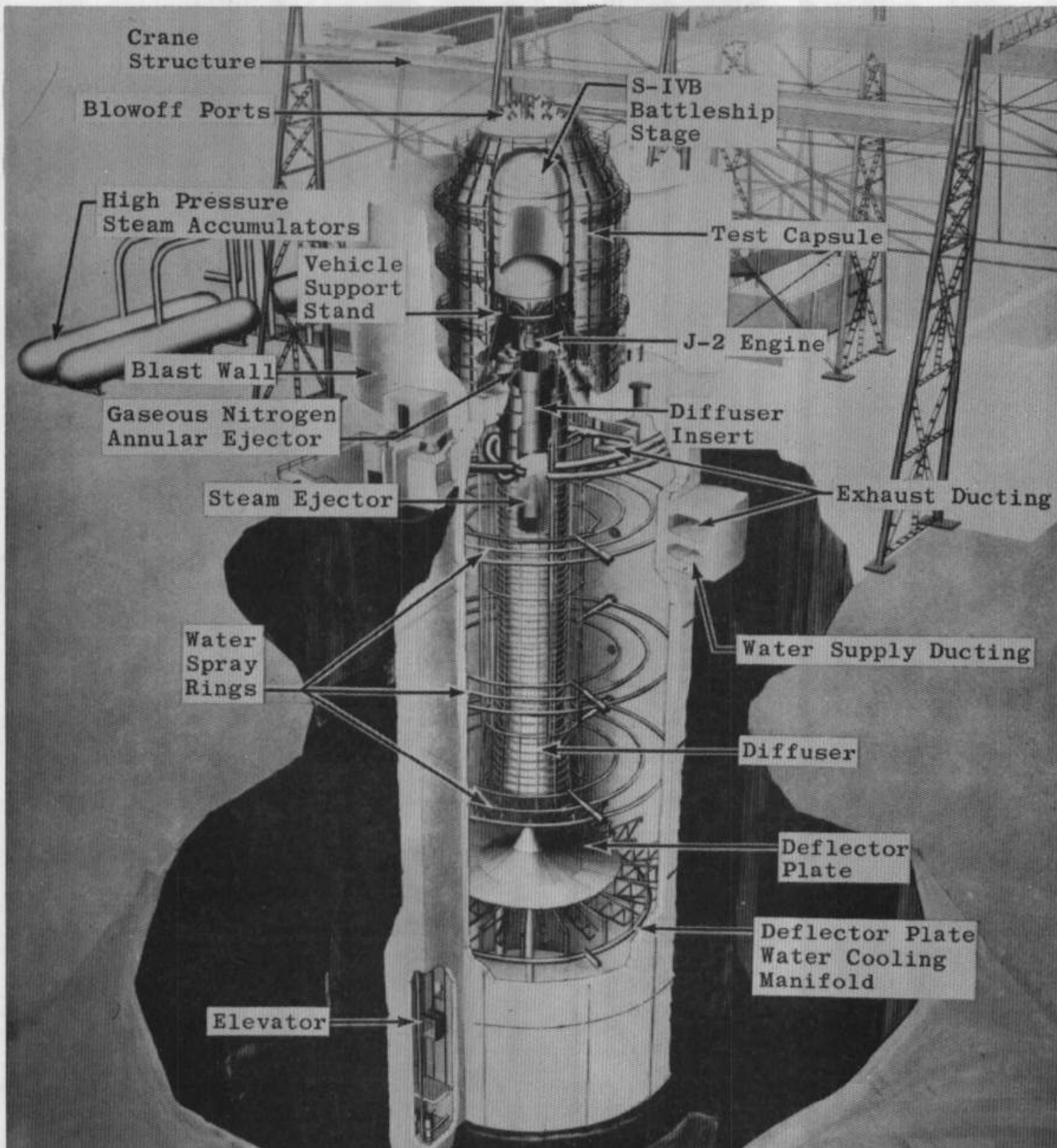


Fig. 2 Test Cell J-4, Artist's Conception

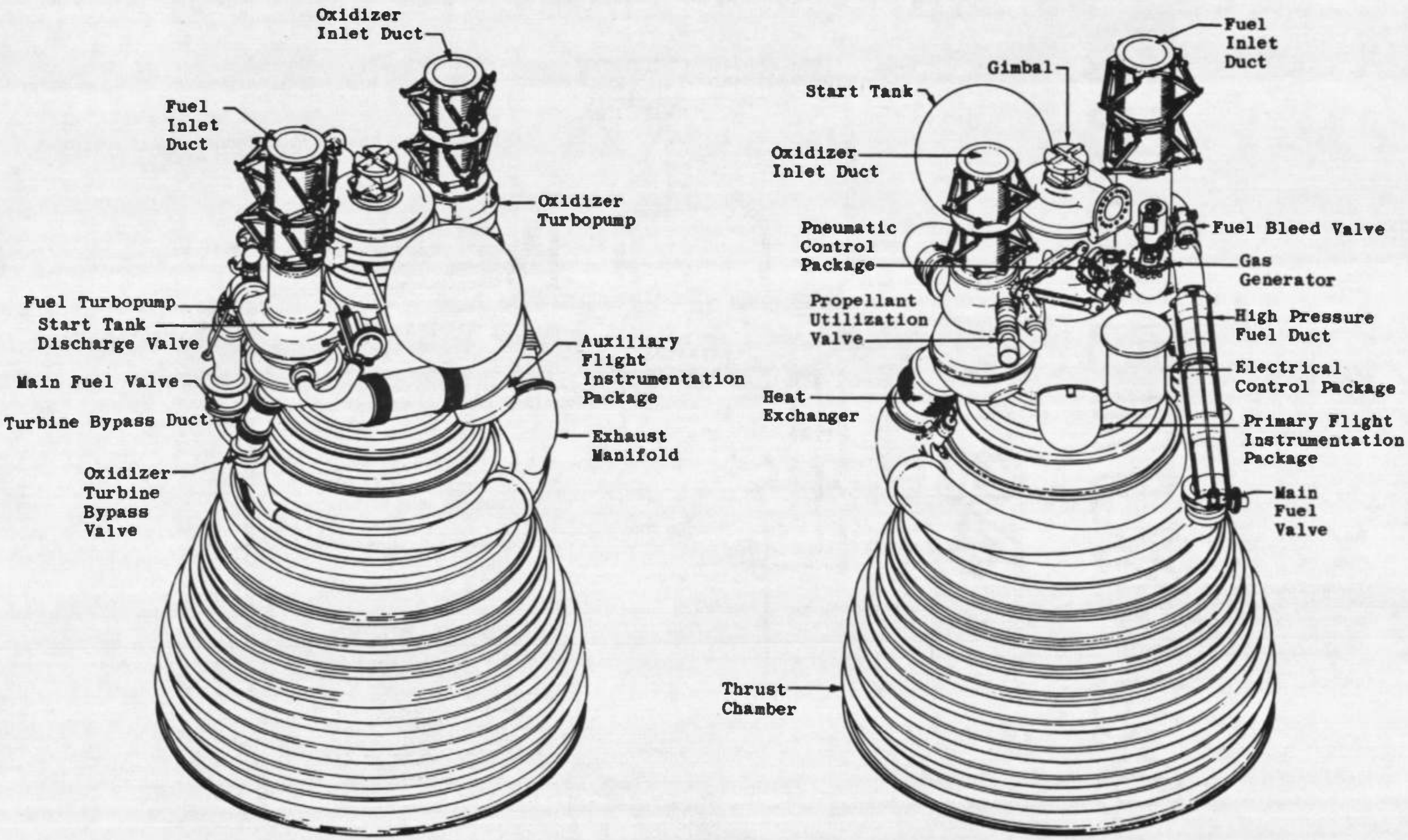


Fig. 3 Engine Details

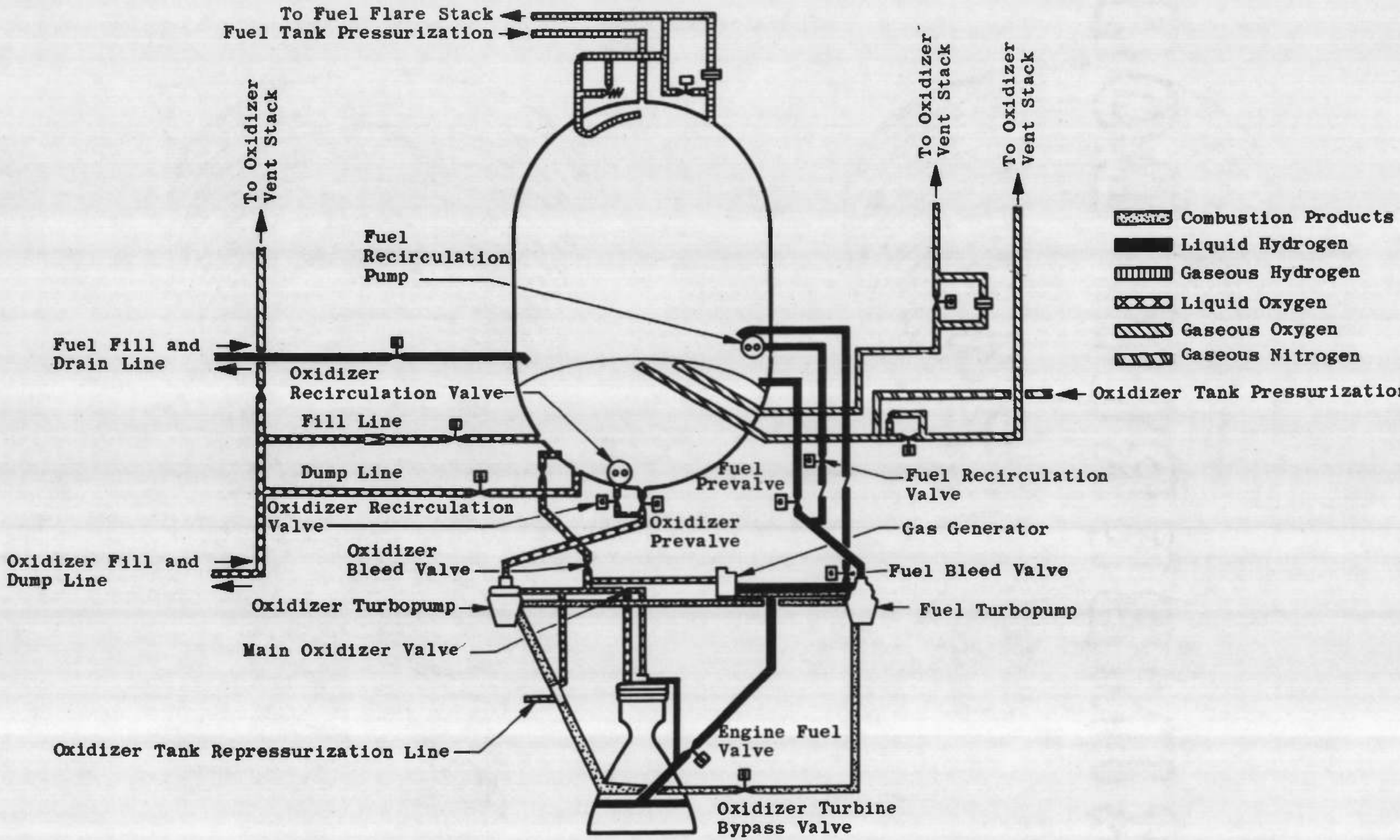


Fig. 4 S-IVB Battleship State/J-2 Rocket Engine Schematic

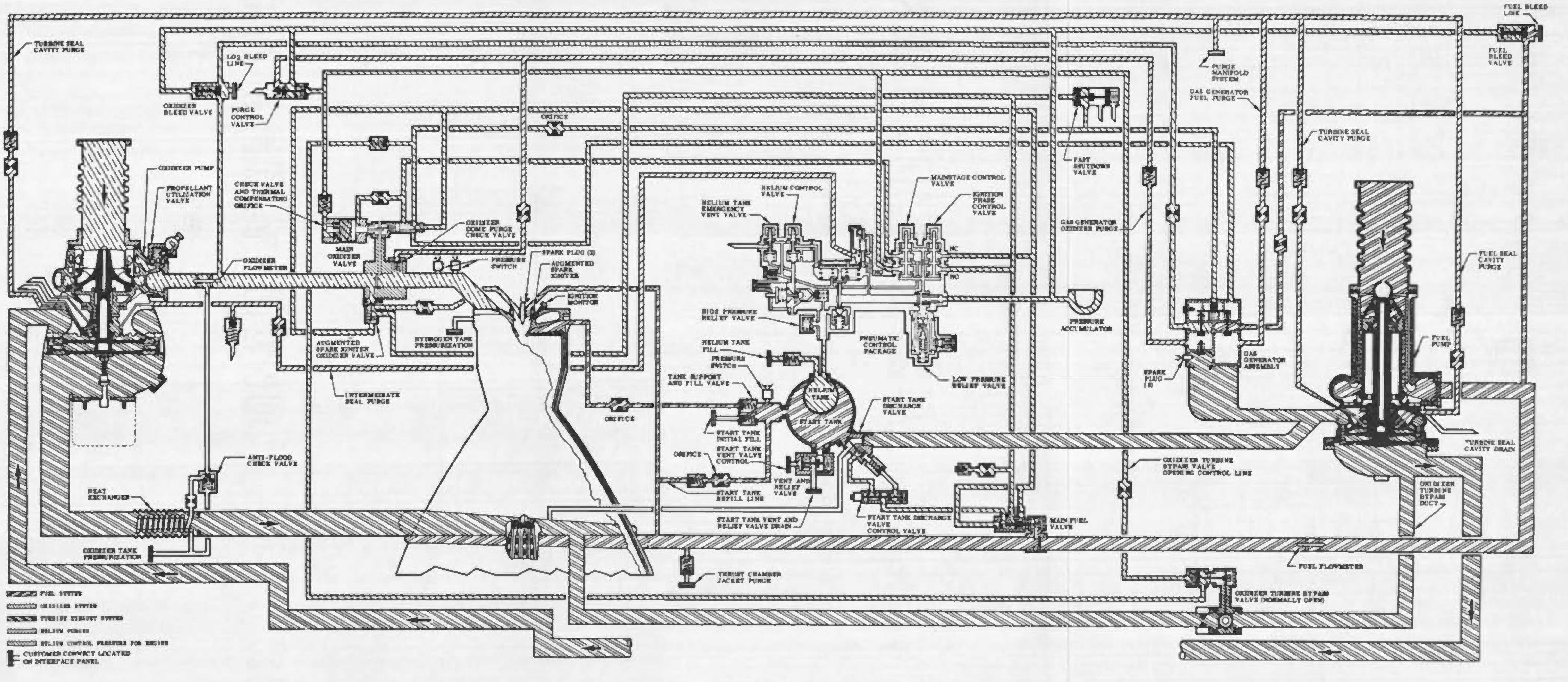


Fig. 5 Engine Schematic

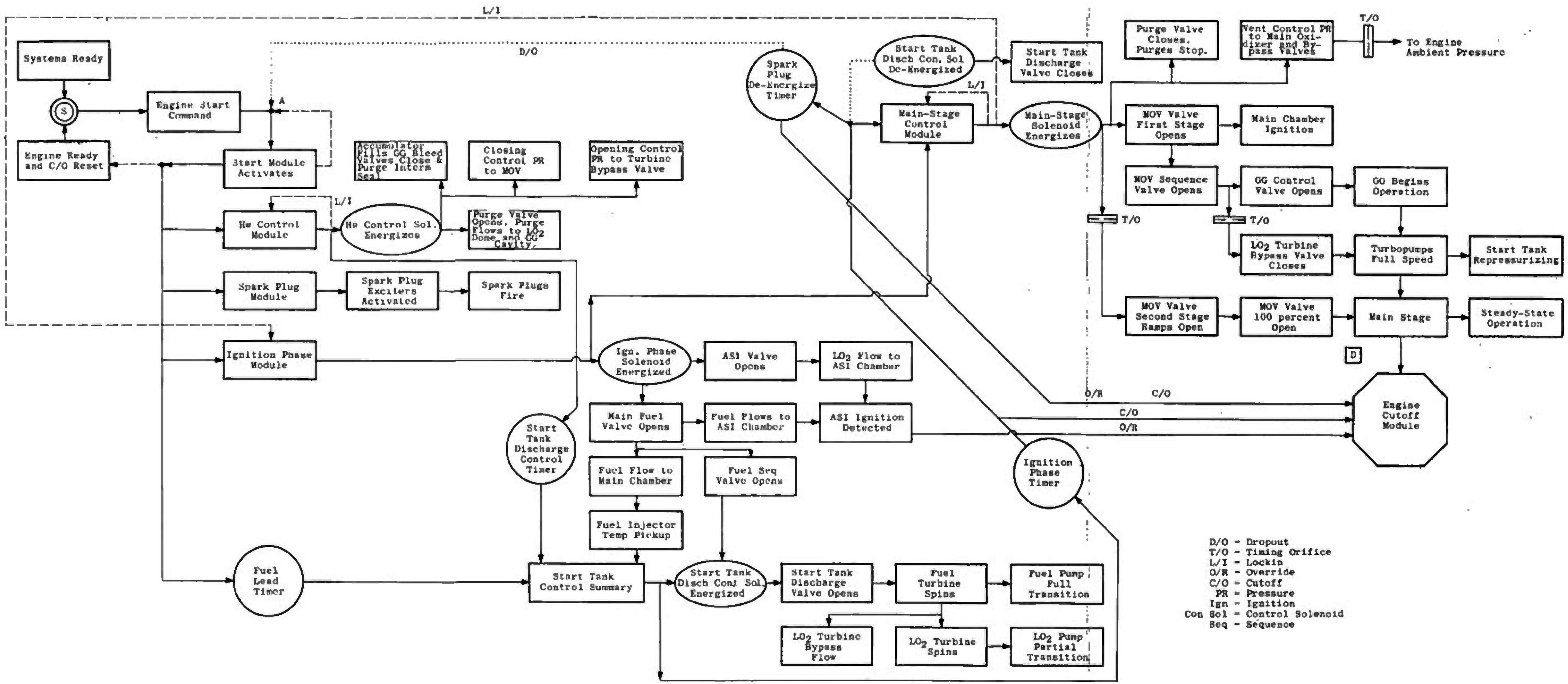
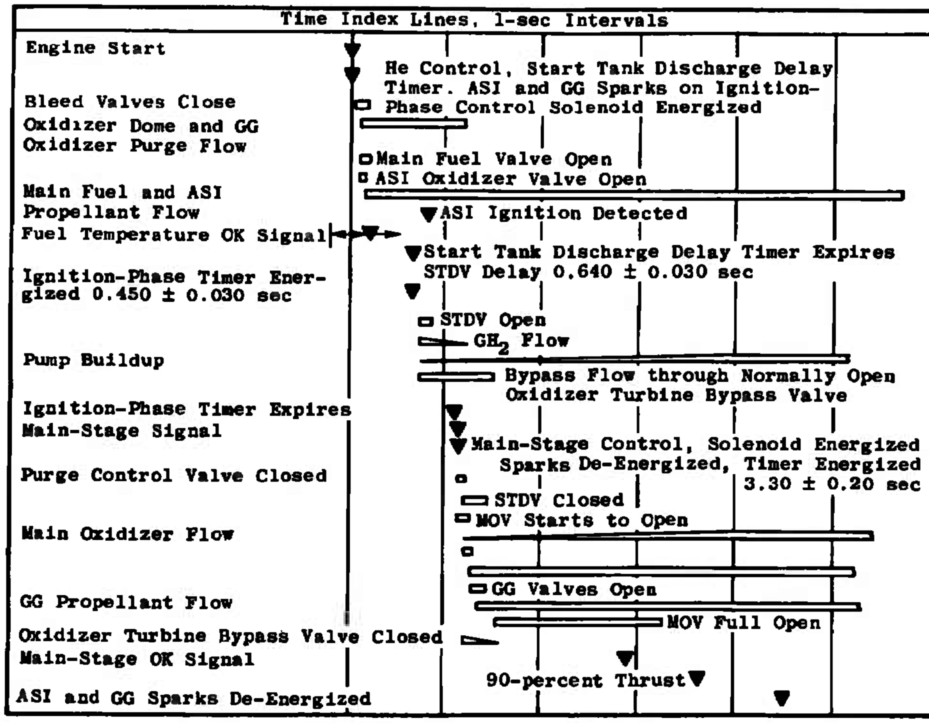
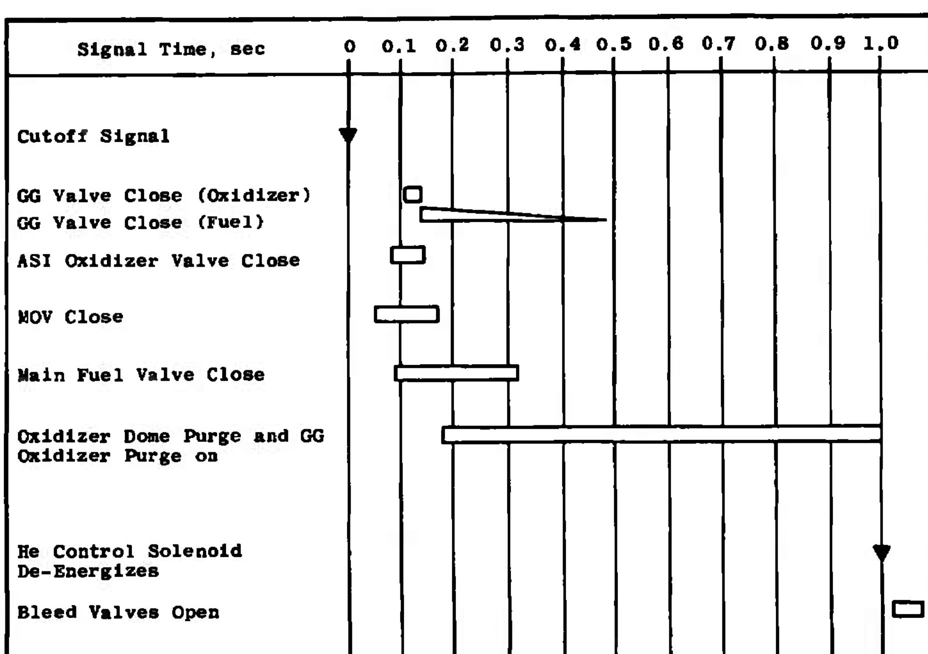


Fig. 6 Engine Start Logic Schematic

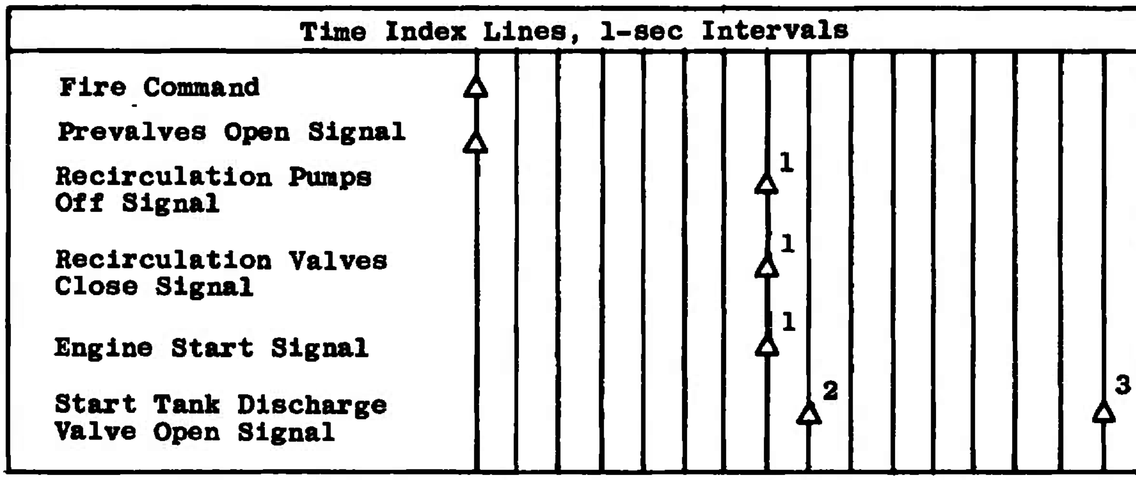


a. Start Sequence



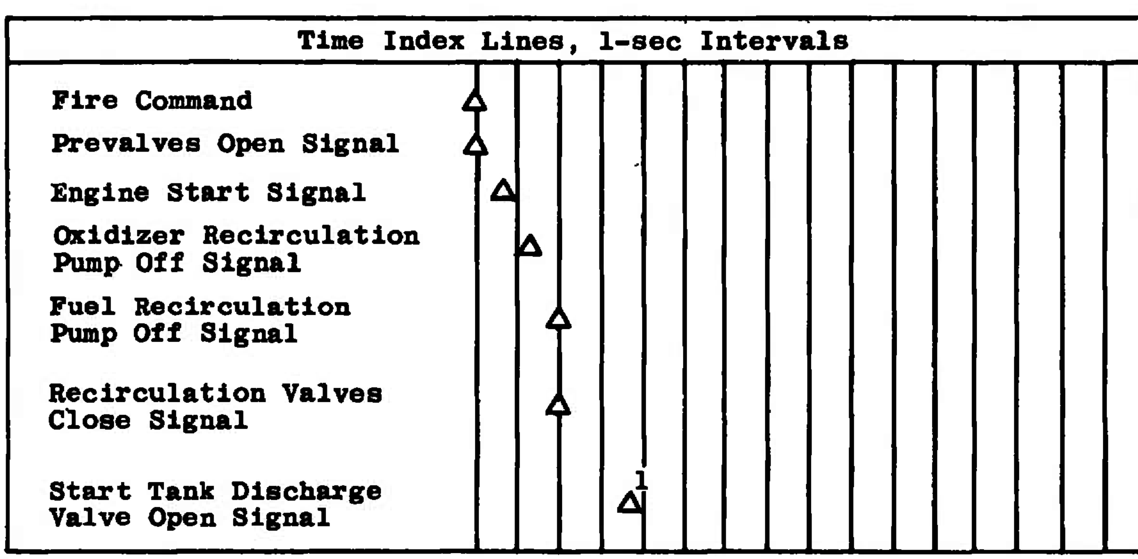
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

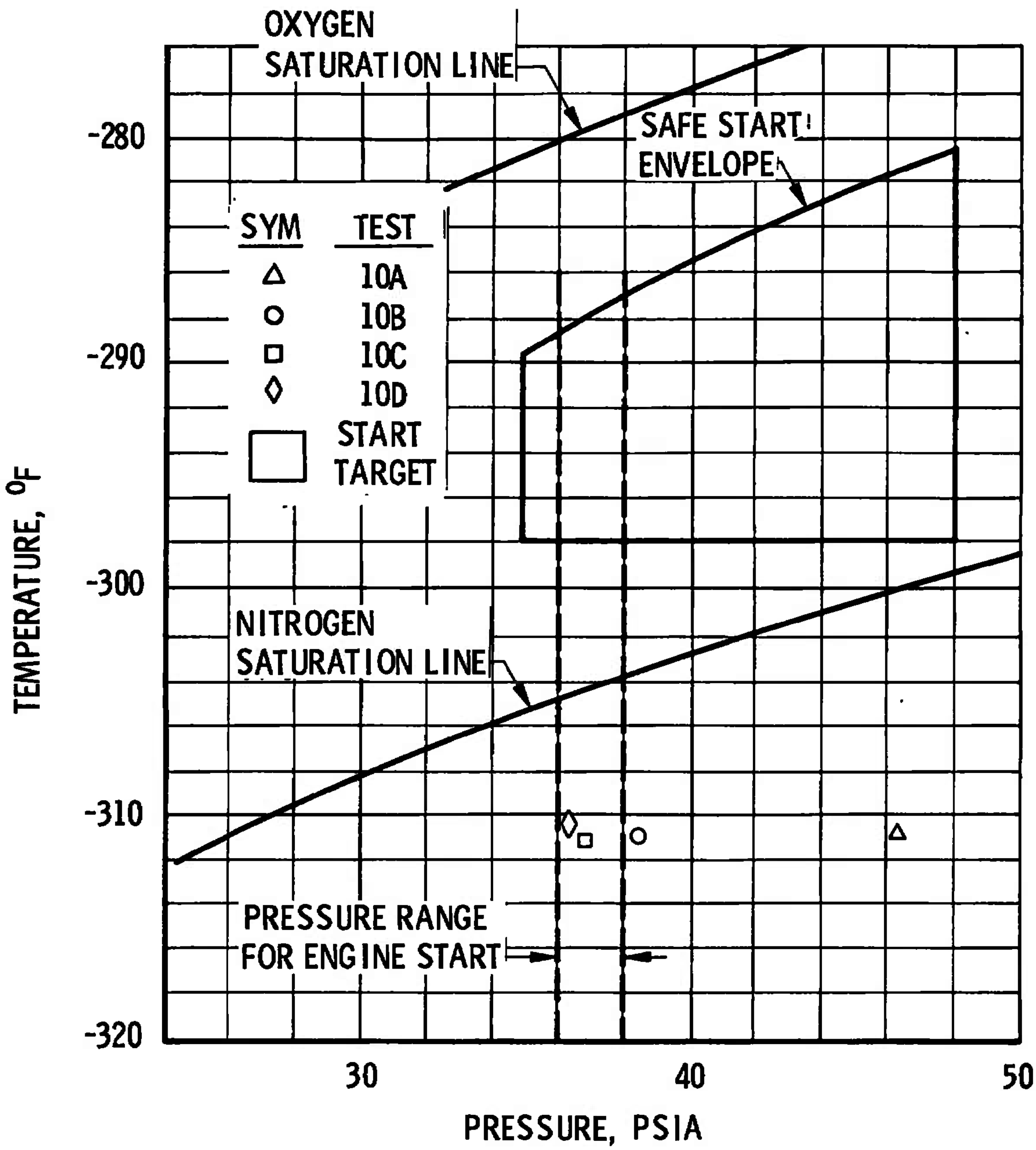
c. "Normal" Start Sequence



[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

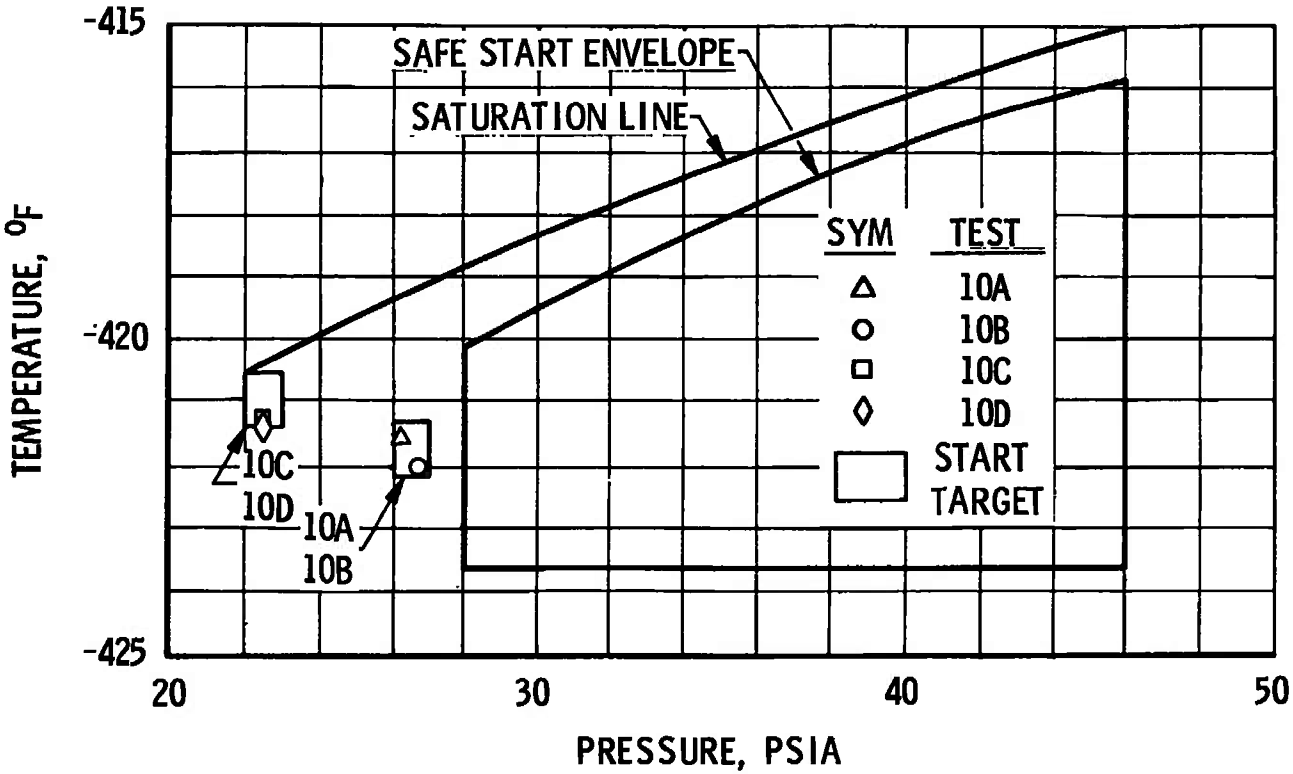
d. "Auxiliary" Start Sequence

Fig. 7 Concluded



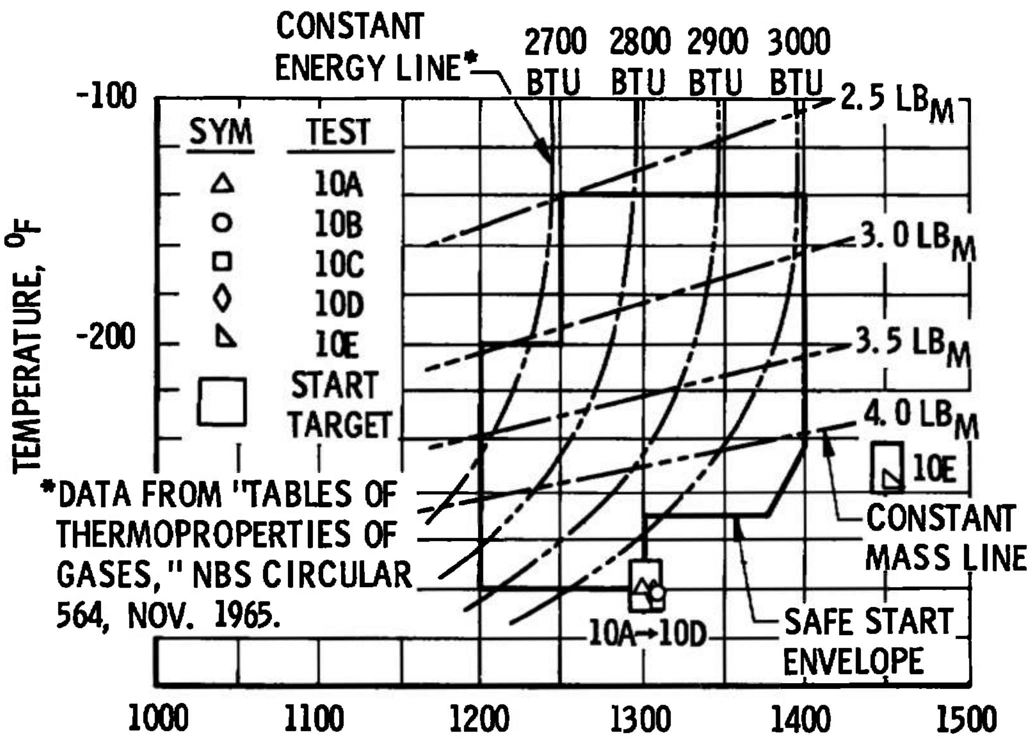
a. Oxidizer Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

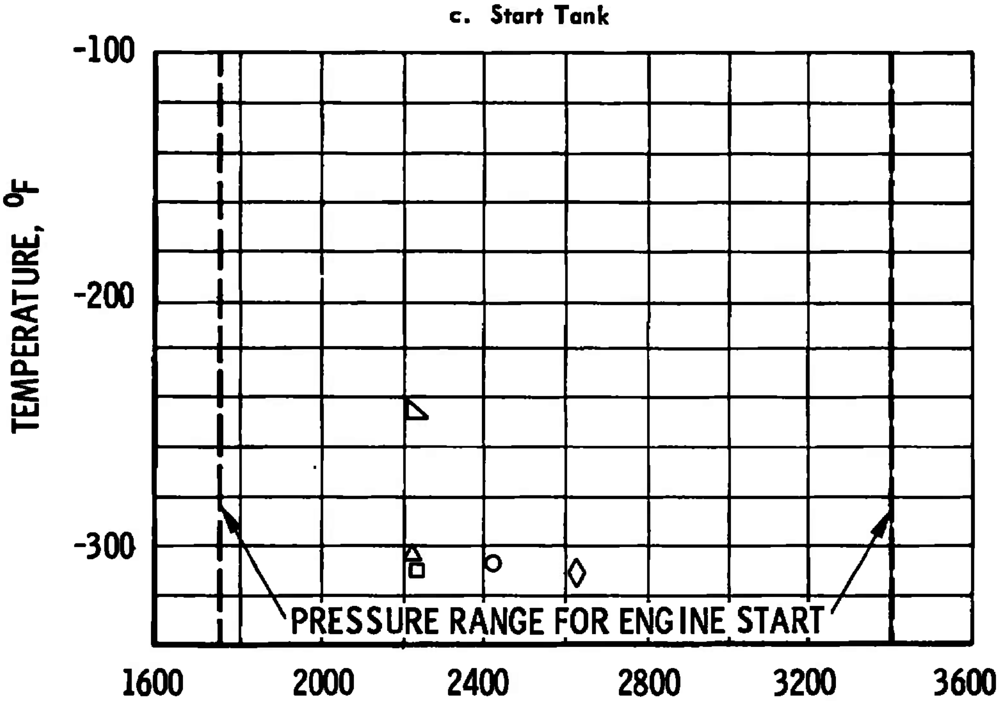


b. Fuel Pump Inlet

Fig. 8 Continued

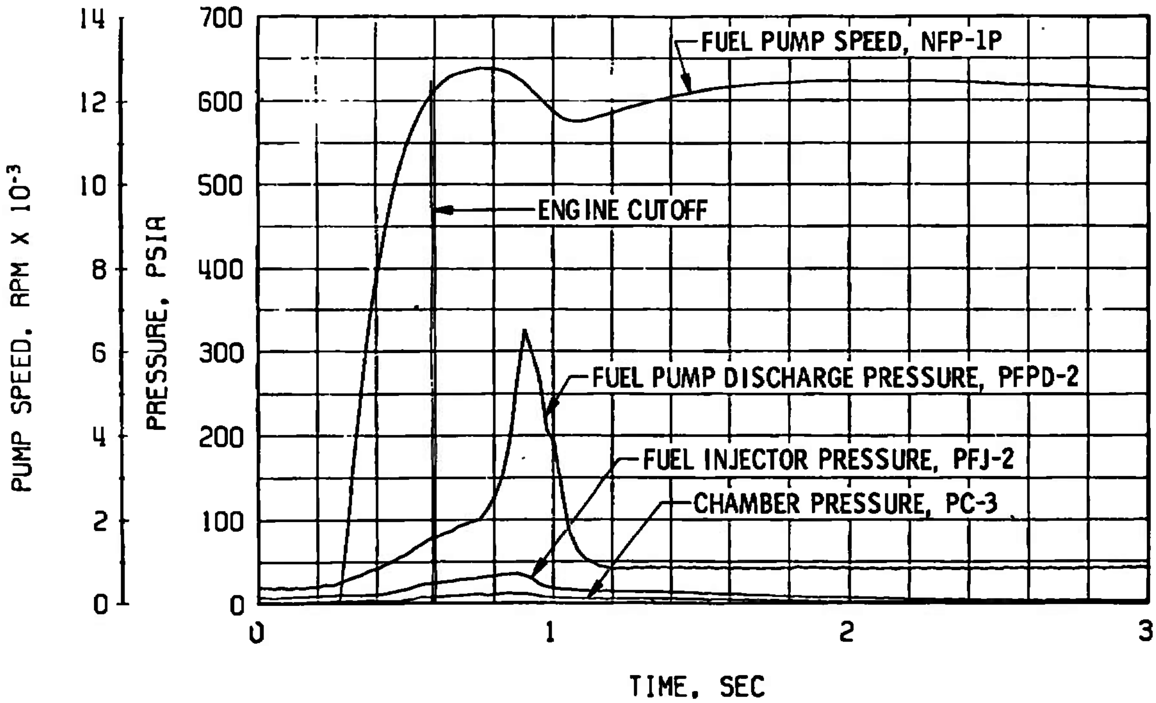


c. Start Tank

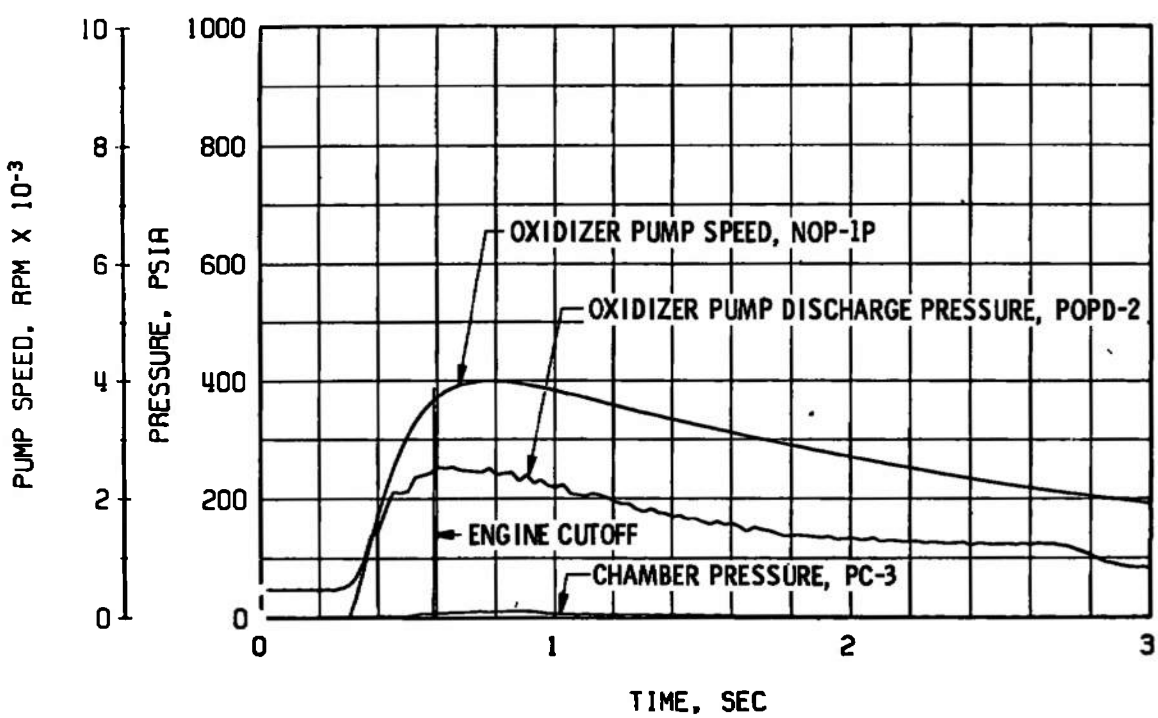


d. Helium Tank

Fig. 8 Concluded



a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 9 Engine Transient Operation, Test 10A

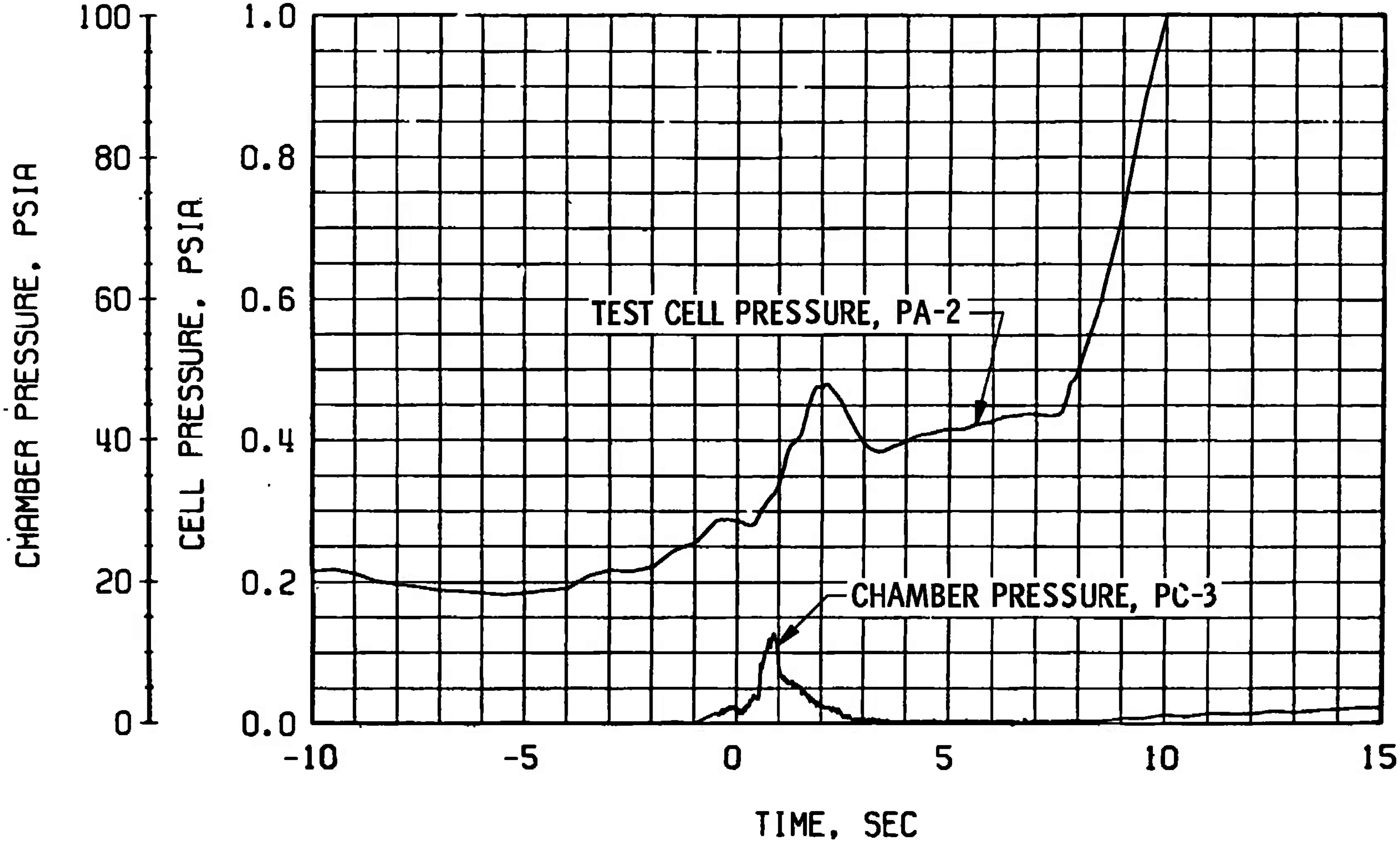
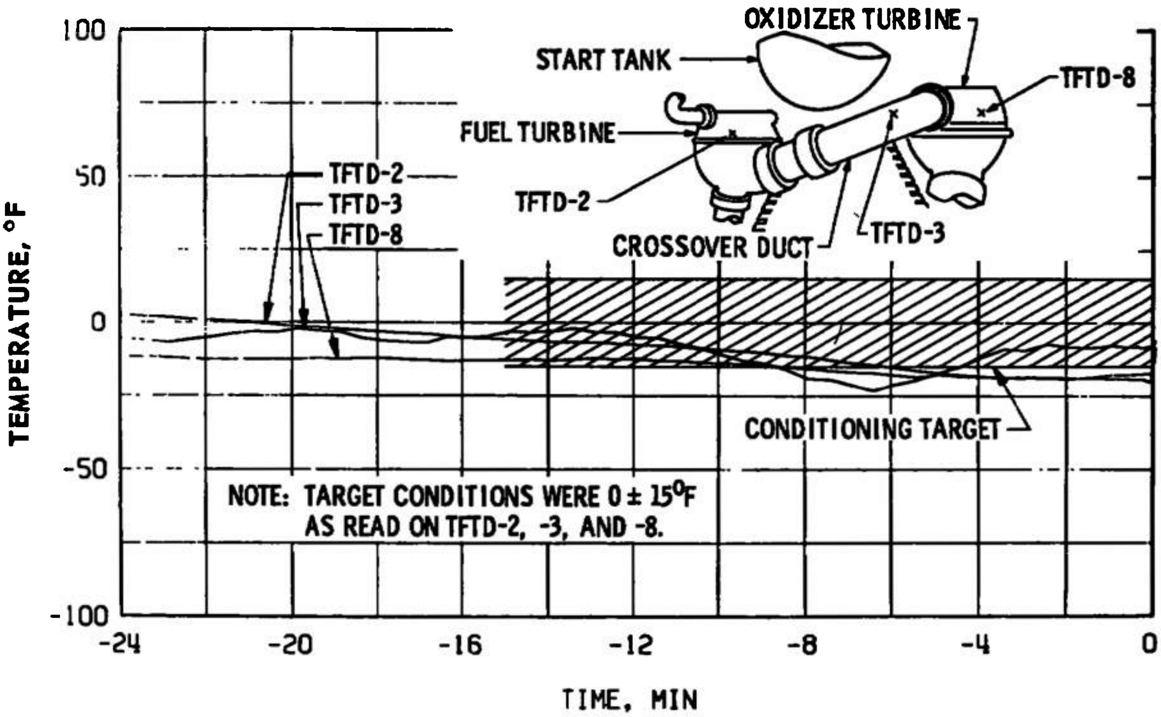
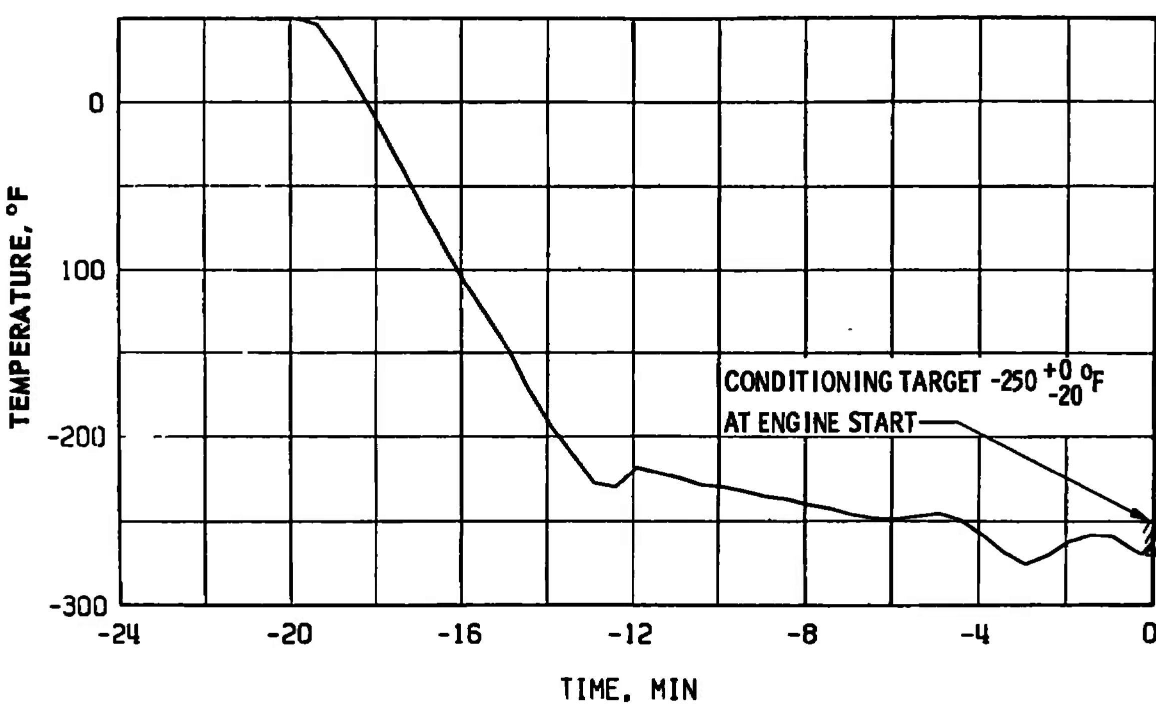


Fig. 10 Engine Ambient and Combustion Chamber Pressure, Test 10A



a. Crossover Duct, TFTD



b. Thrust Chamber Throat, TSC2-19

Fig. 11 Thermal Conditioning History of Engine Components, Test 10A

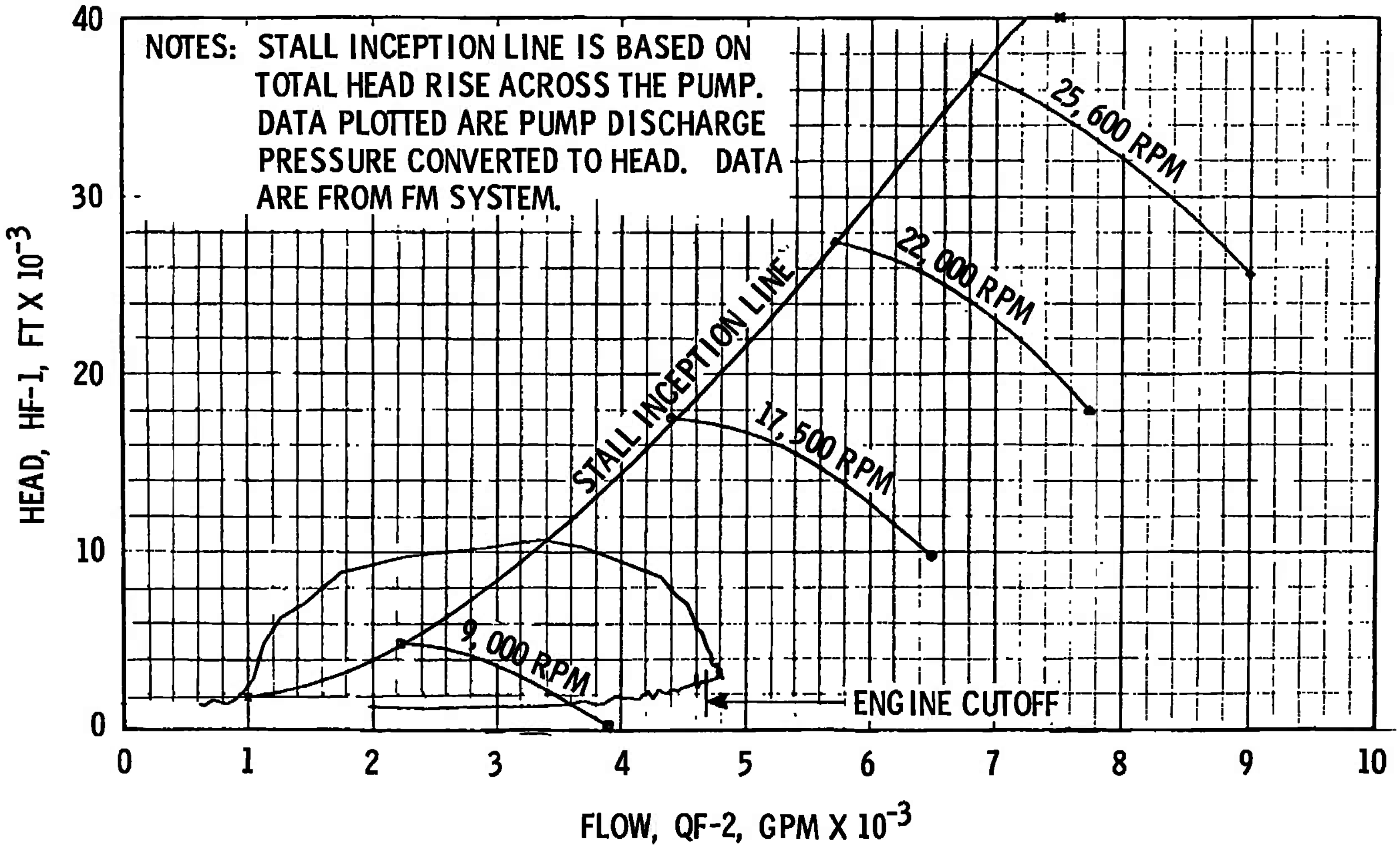
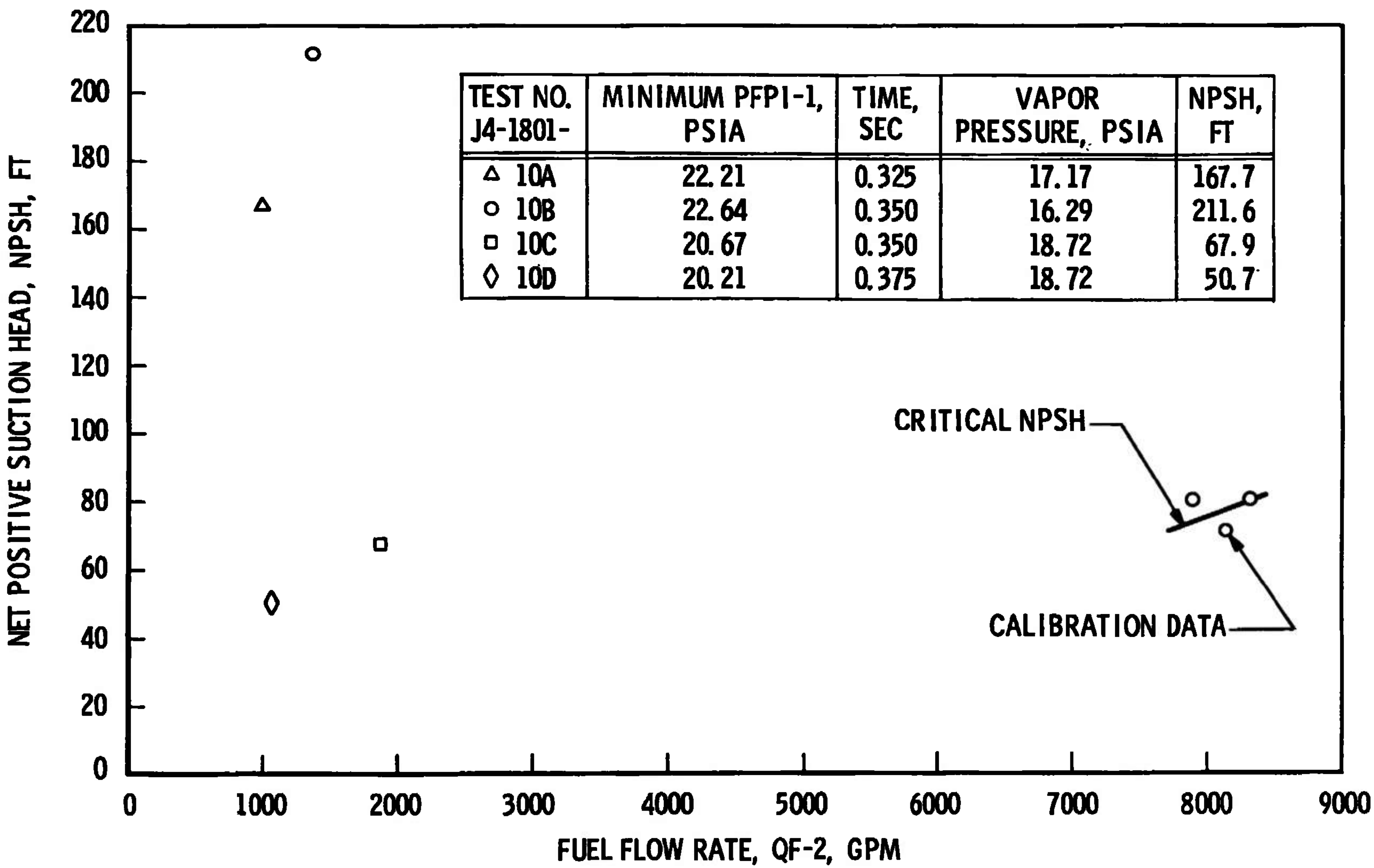
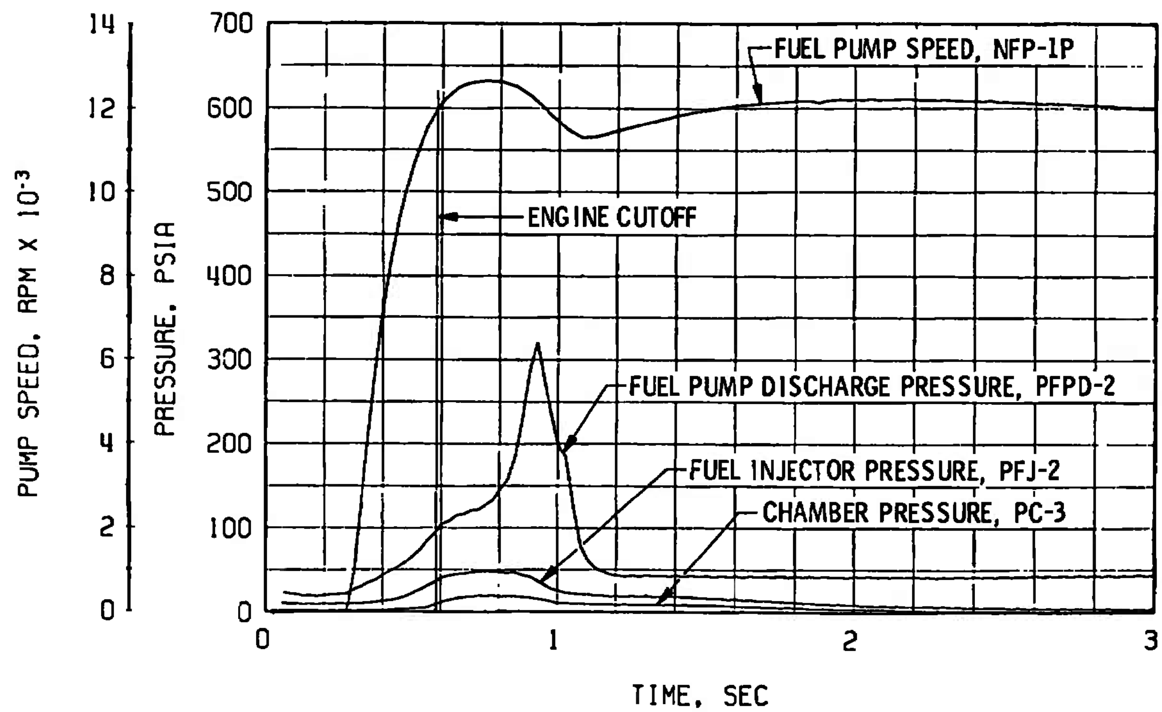


Fig. 12 Fuel Pump Start Transient Performance, Test 10A

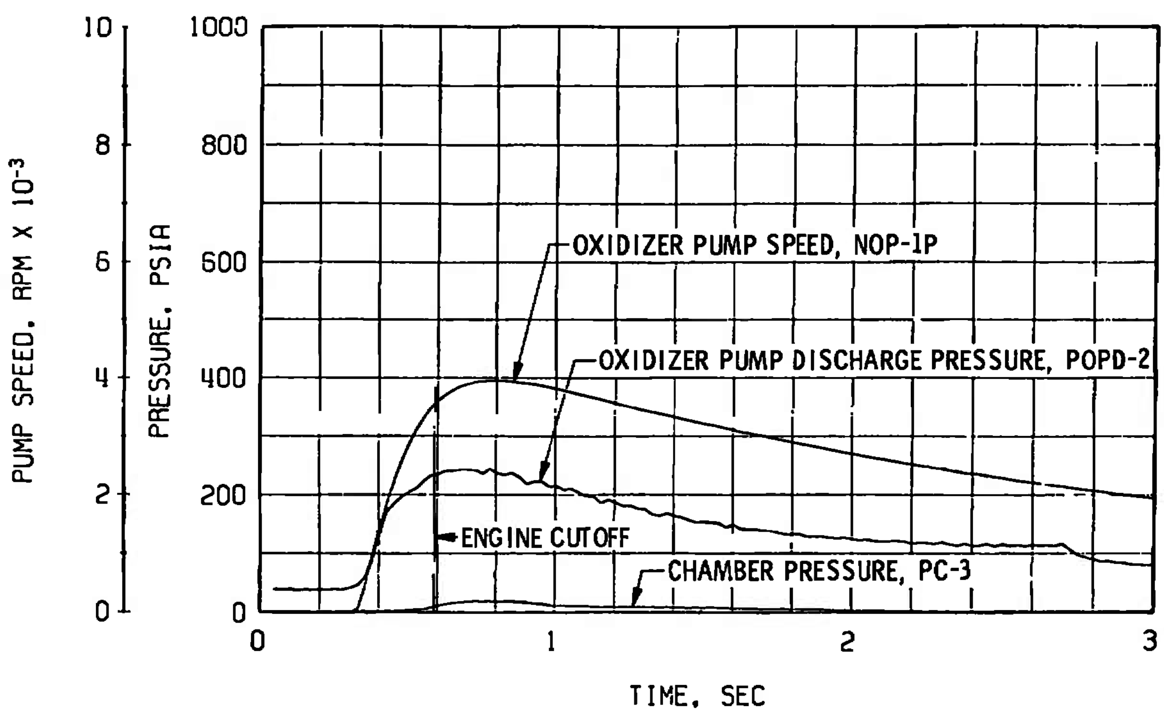


TEST NO. J4-1801-	MINIMUM PFPI-1, PSIA	TIME, SEC	VAPOR PRESSURE, PSIA	NPSH, FT
△ 10A	22.21	0.325	17.17	167.7
○ 10B	22.64	0.350	16.29	211.6
□ 10C	20.67	0.350	18.72	67.9
◇ 10D	20.21	0.375	18.72	50.7

Fig. 13 Fuel Pump Net Positive Suction Head for Tests 10A to 10D



a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 14 Engine Transient Operation, Test 10B

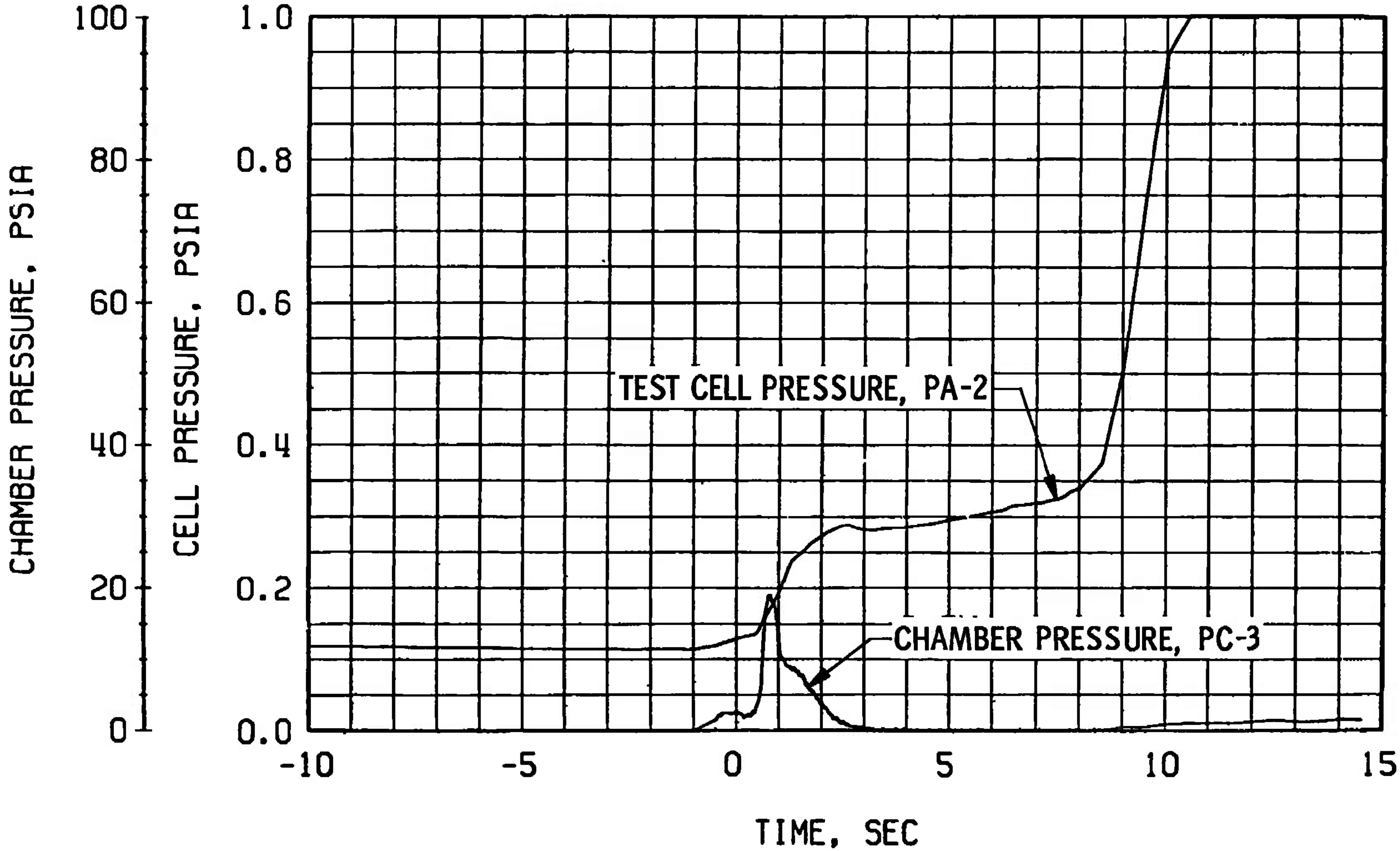
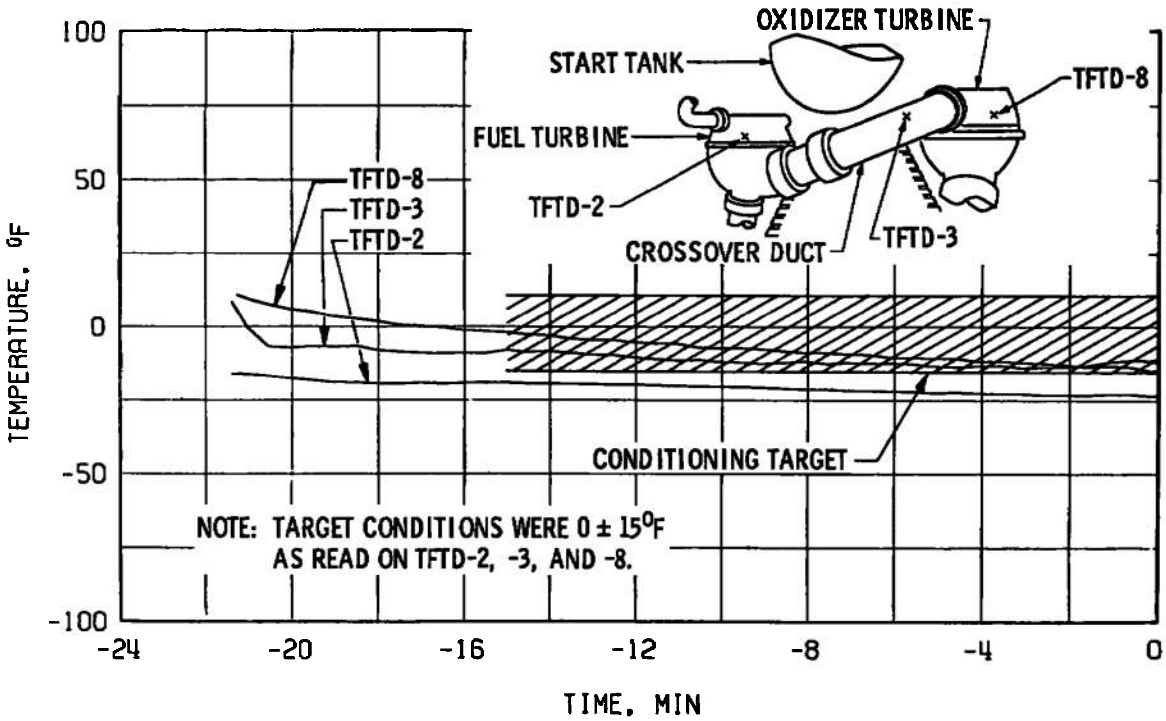
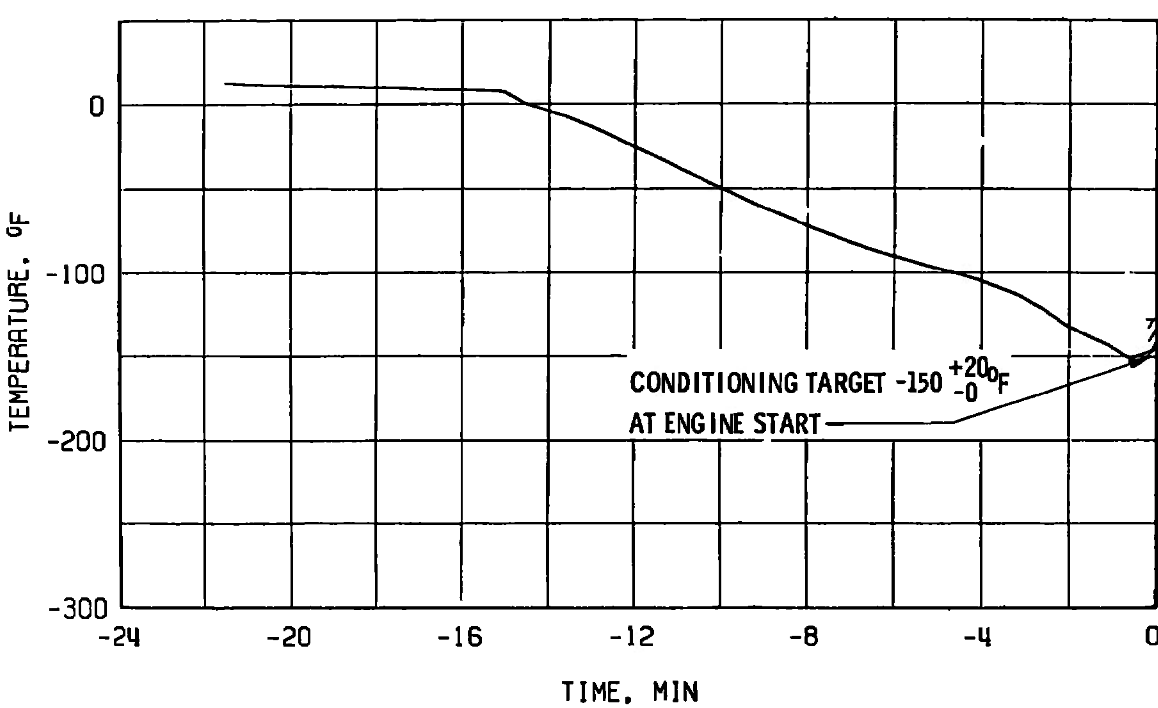


Fig. 15 Engine Ambient and Combustion Chamber Pressures, Test 10B



a. Crossover Duct, TFTD



b. Thrust Chamber Throat, TSC2-19

Fig. 16 Thermal Conditioning History of Engine Components, Test 10B

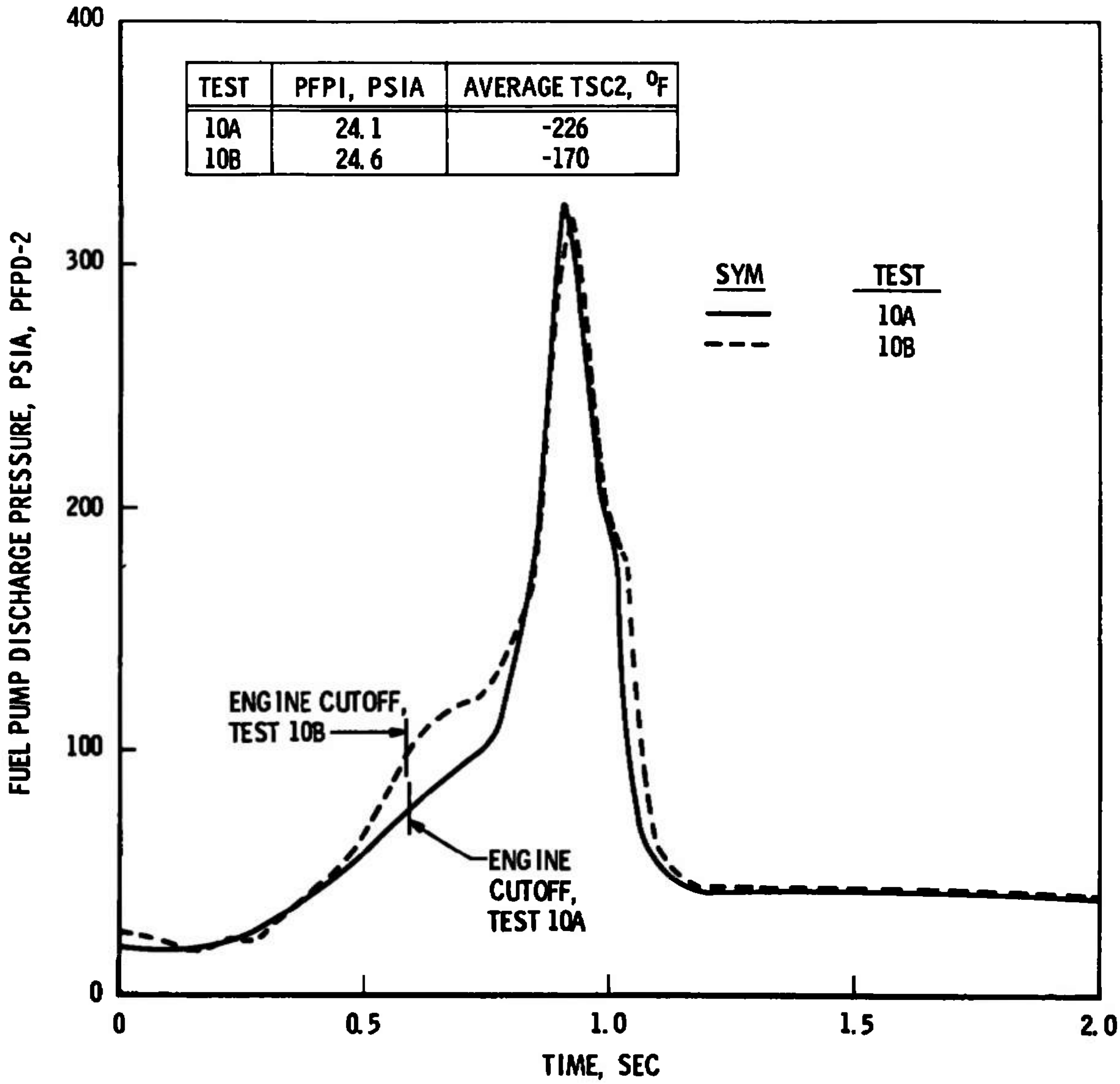


Fig. 17 Comparison of Fuel Pump Discharge Pressure for Tests 10A and 10B

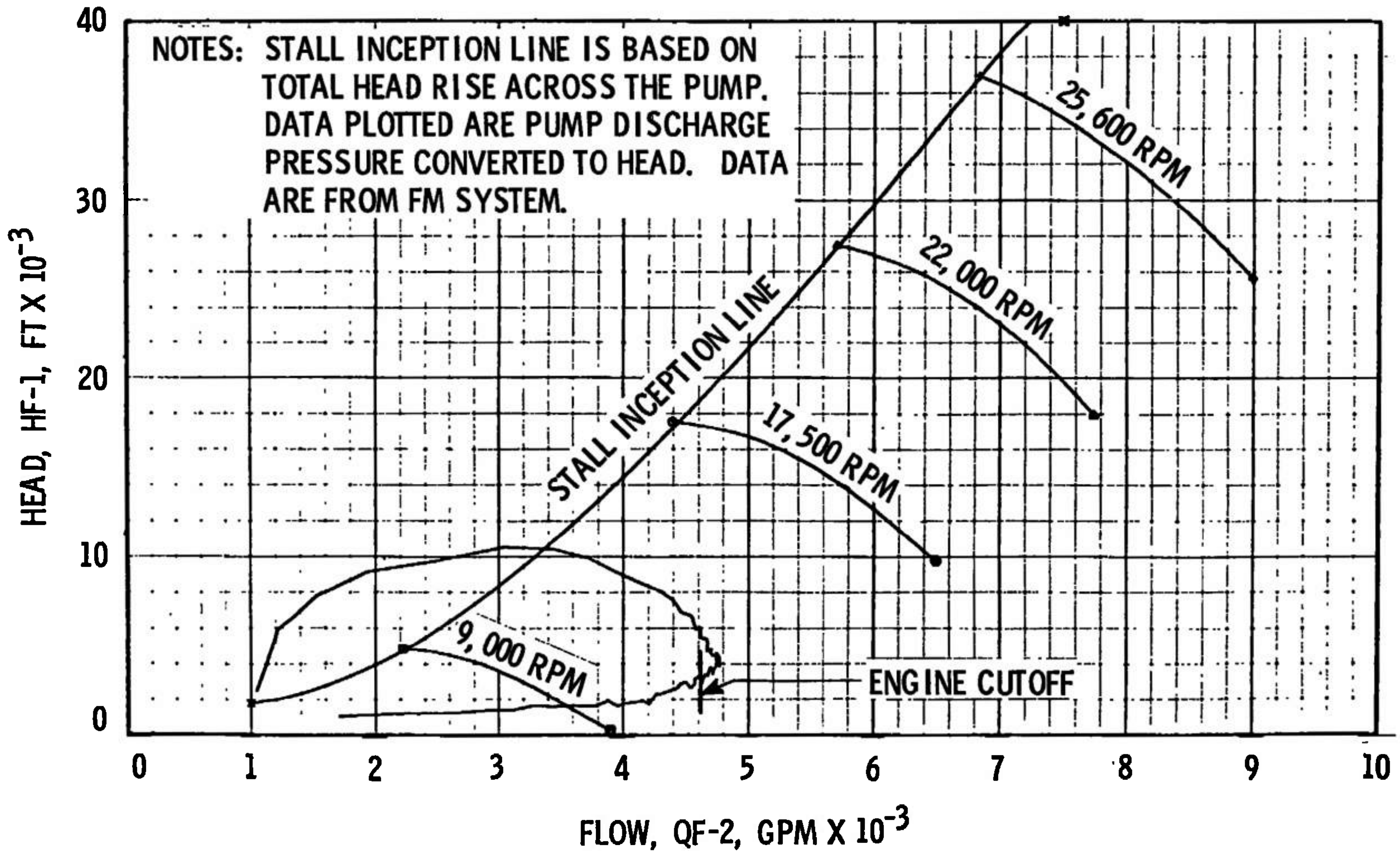
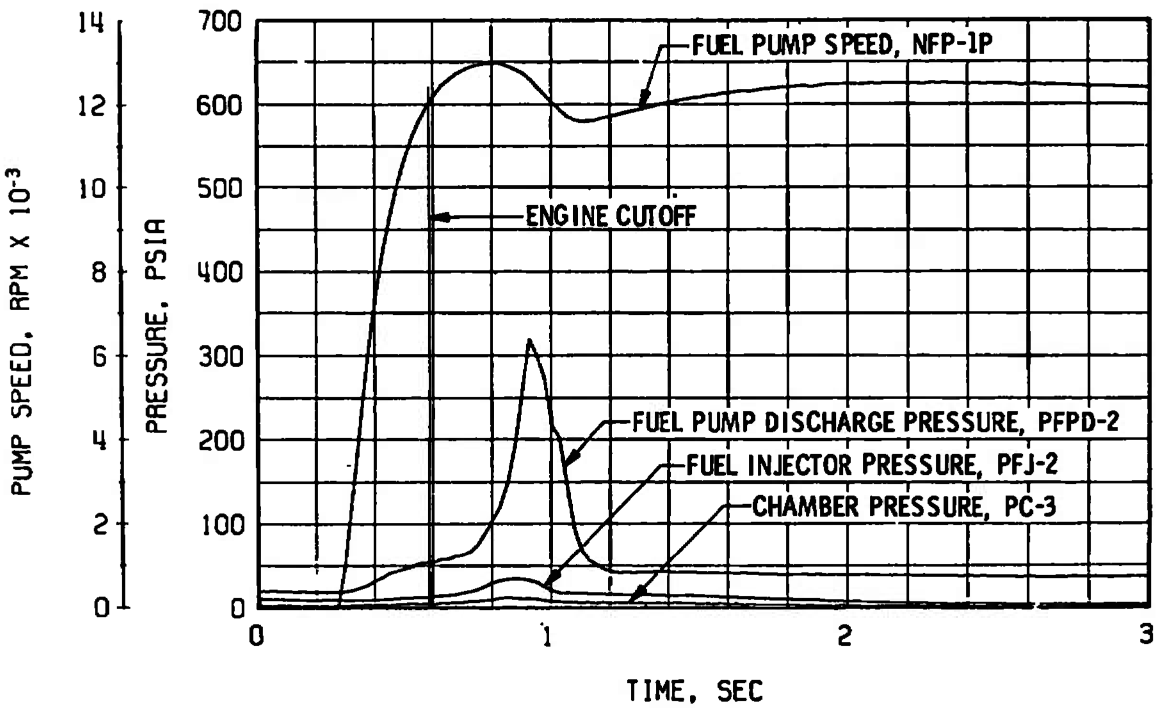
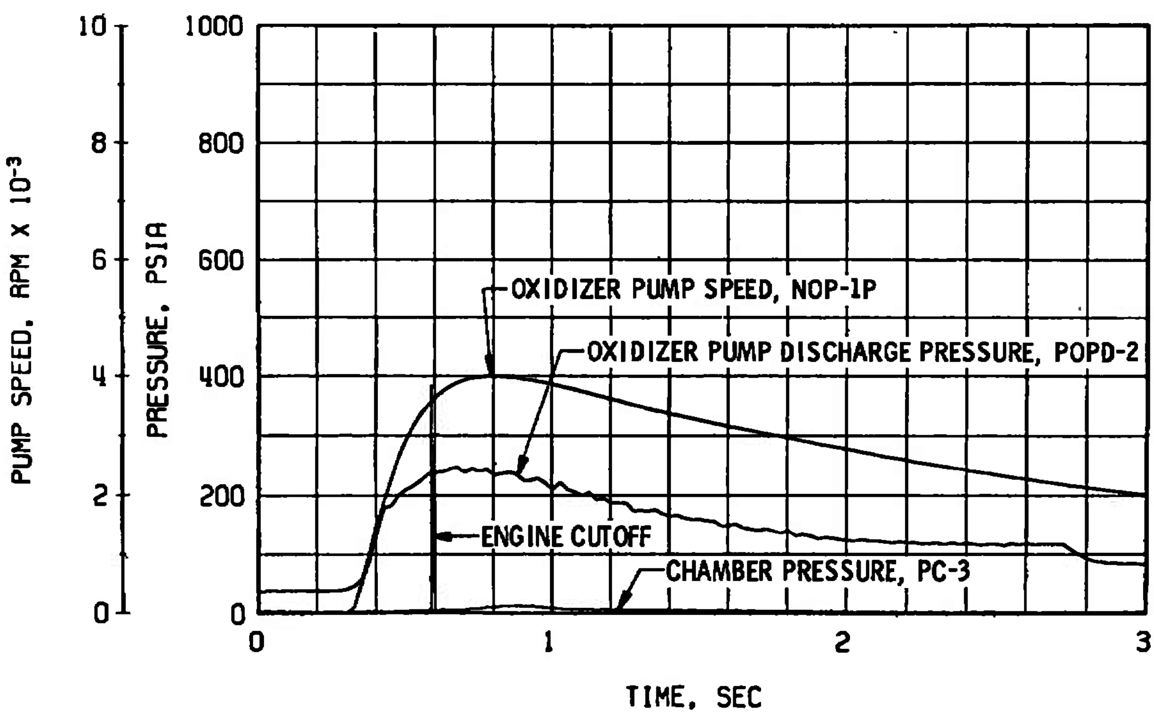


Fig. 18 Fuel Pump Start Transient Performance, Test 10B



a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 19 Engine Transient Operation, Test 10C

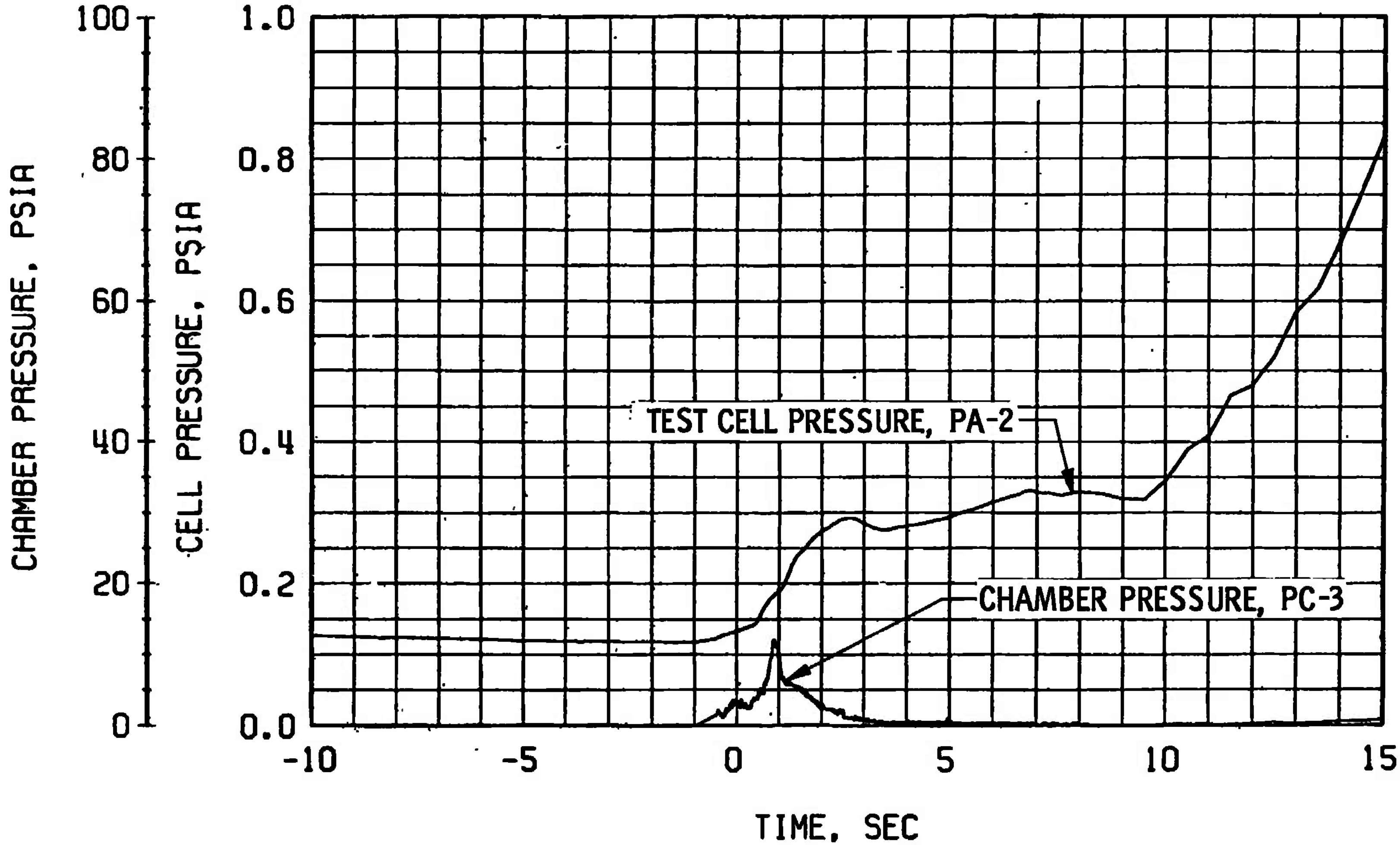
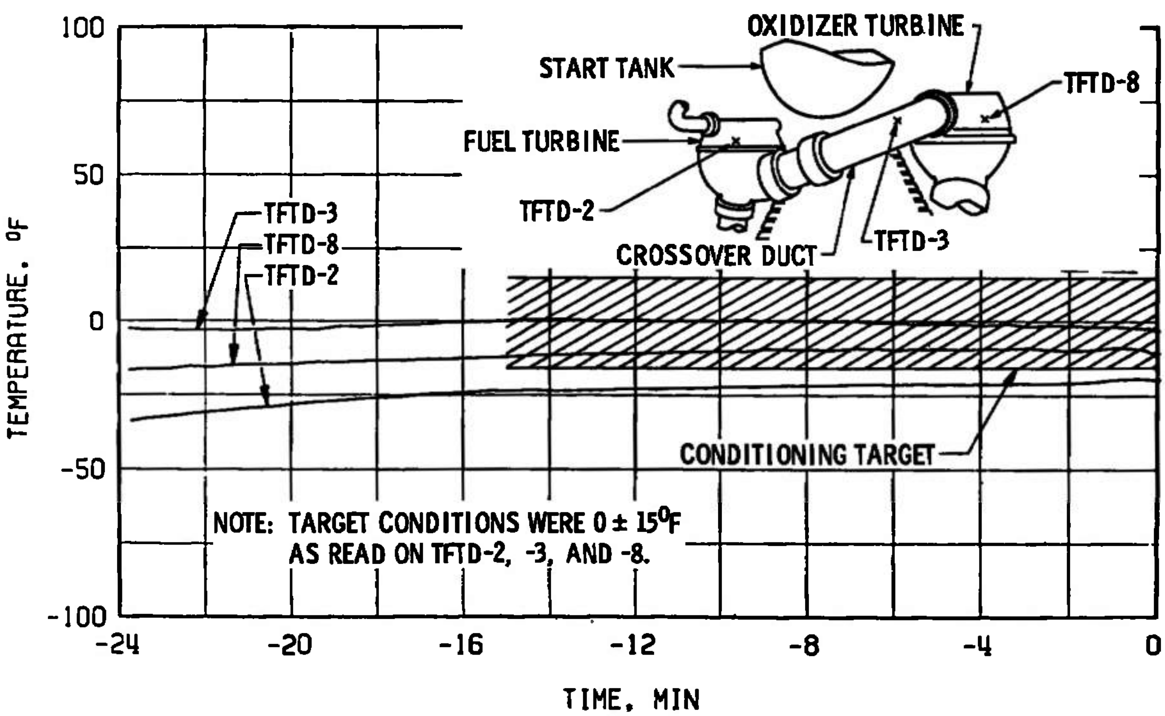
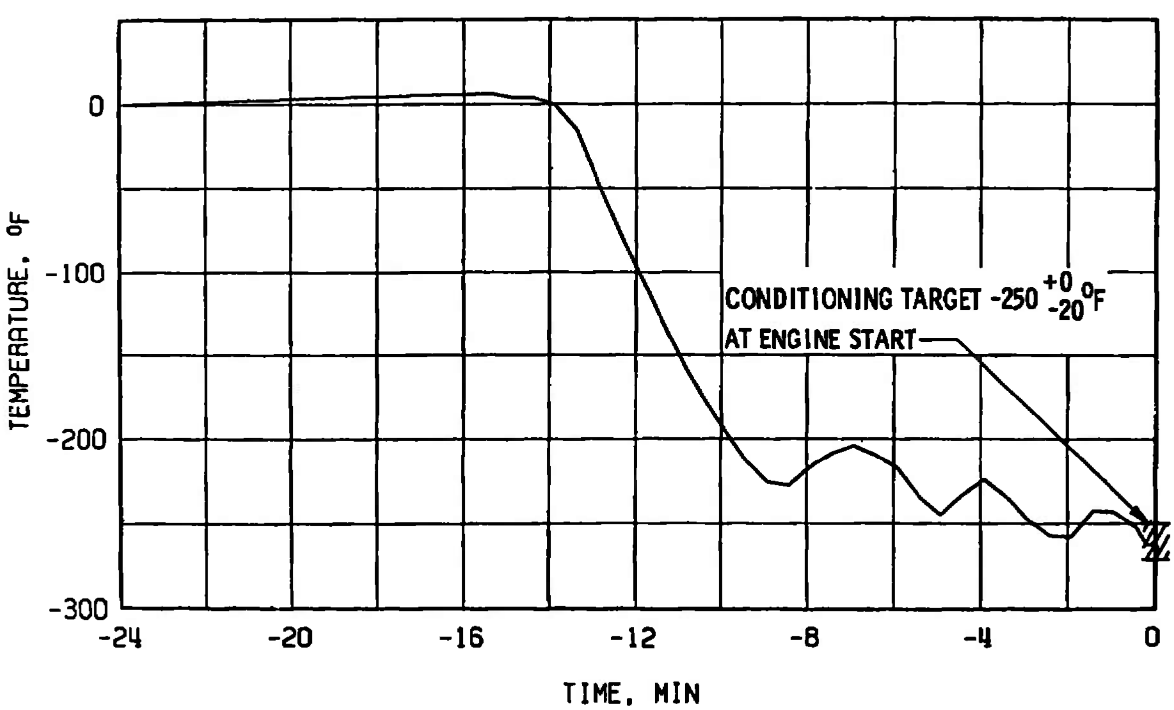


Fig. 20 Engine Ambient and Combustion Chamber Pressure, Test 10C



a. Crossover Duct, TFTD



b. Thrust Chamber Throat, TSC2-19

Fig. 21 Thermal Conditioning History of Engine Components, Test 10C

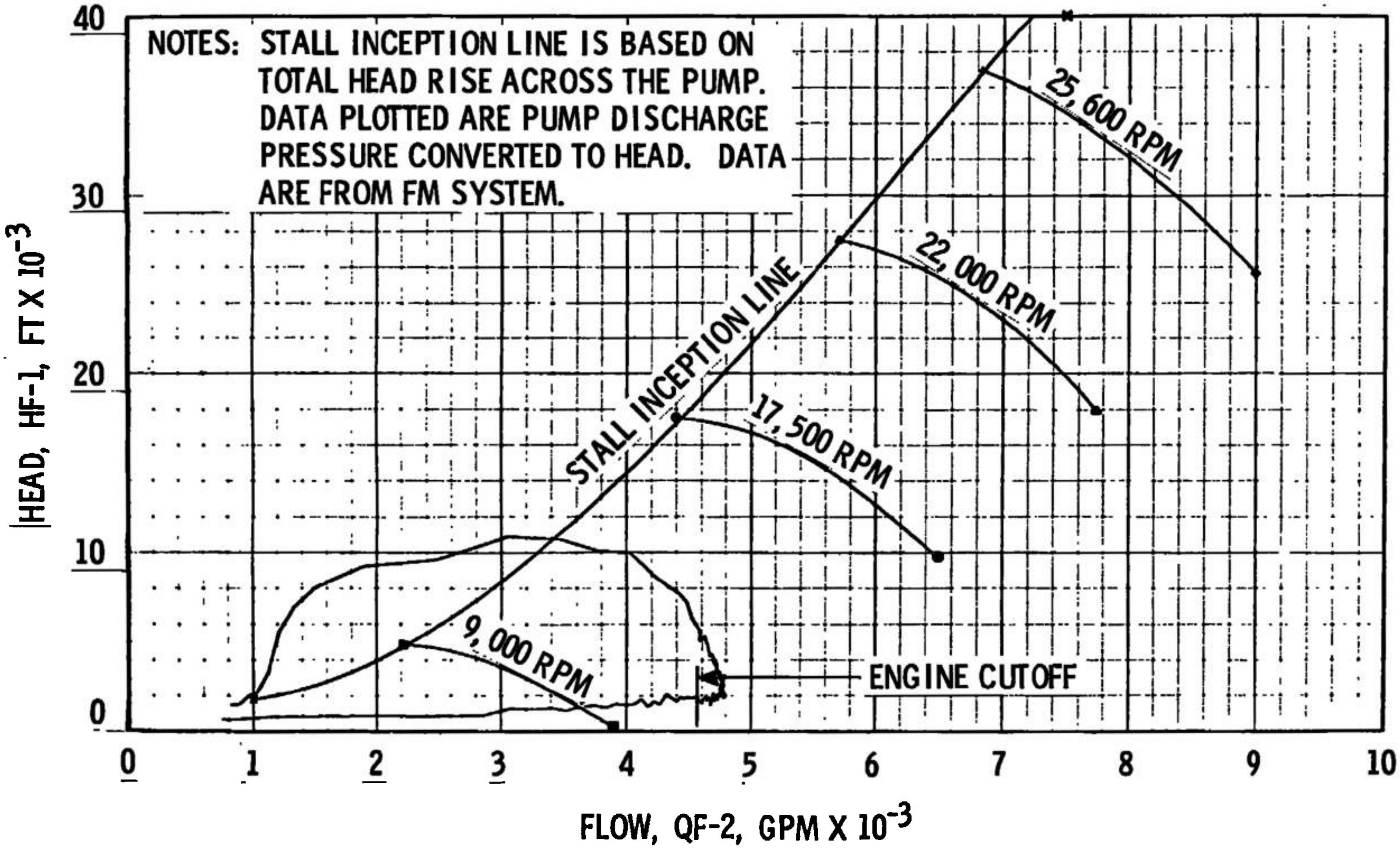
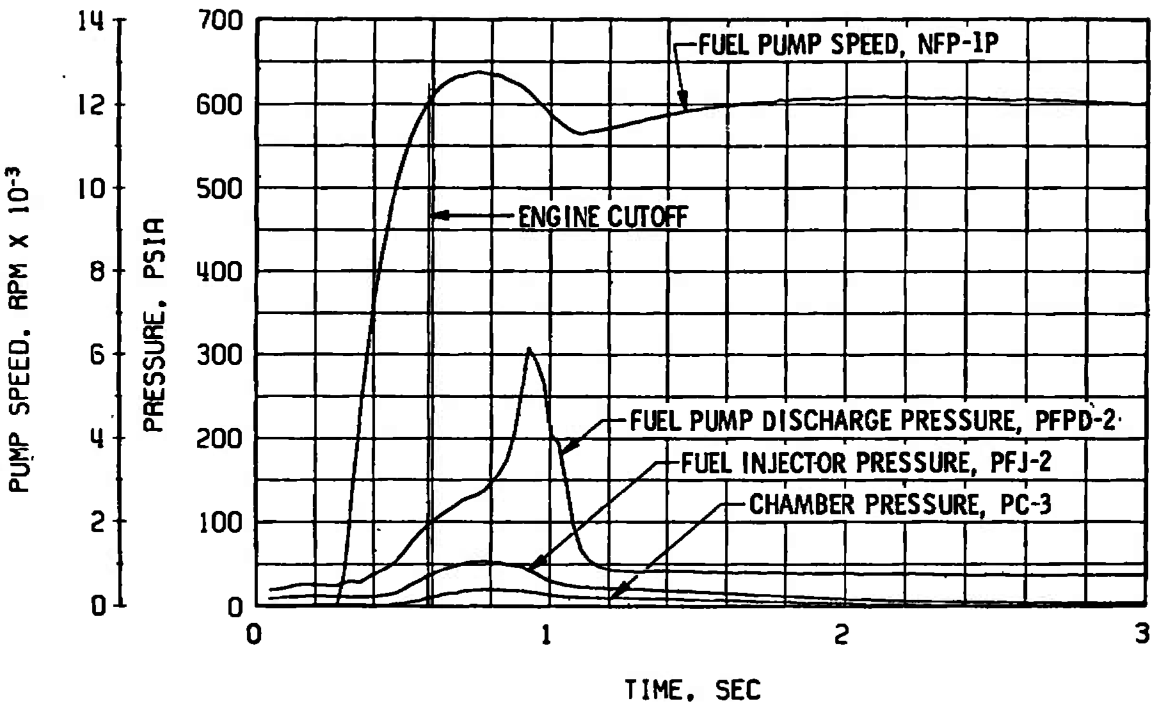
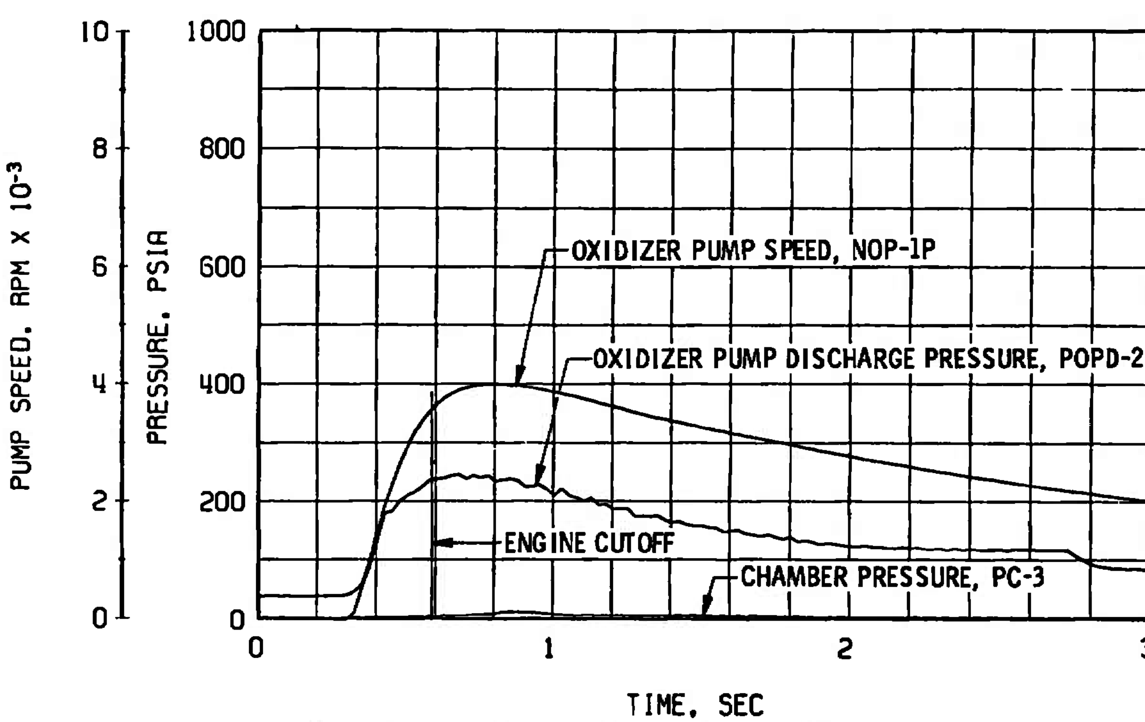


Fig. 22 Fuel Pump Start Transient Performance, Test 10C



a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 23 Engine Transient Operation, Test 10D

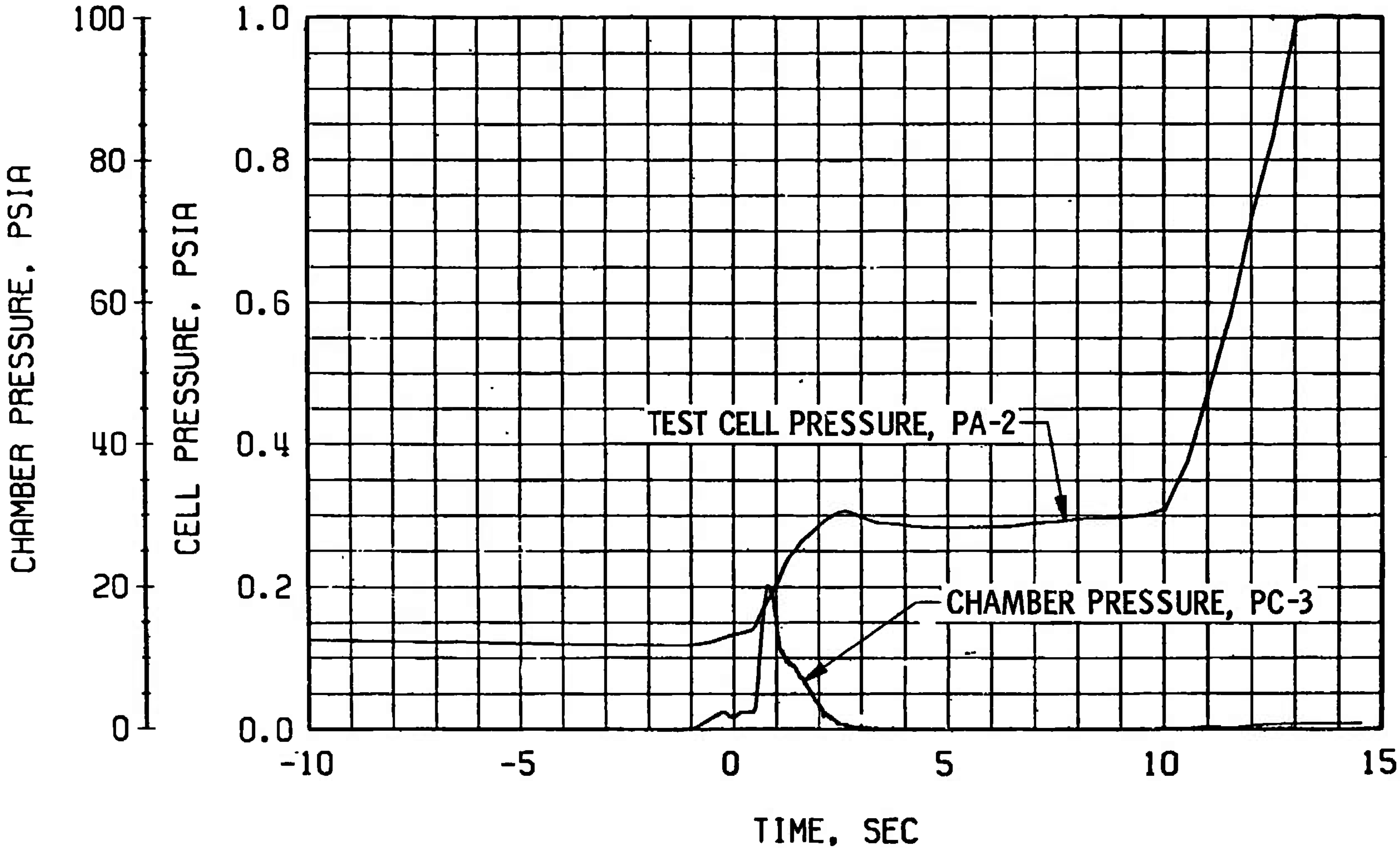
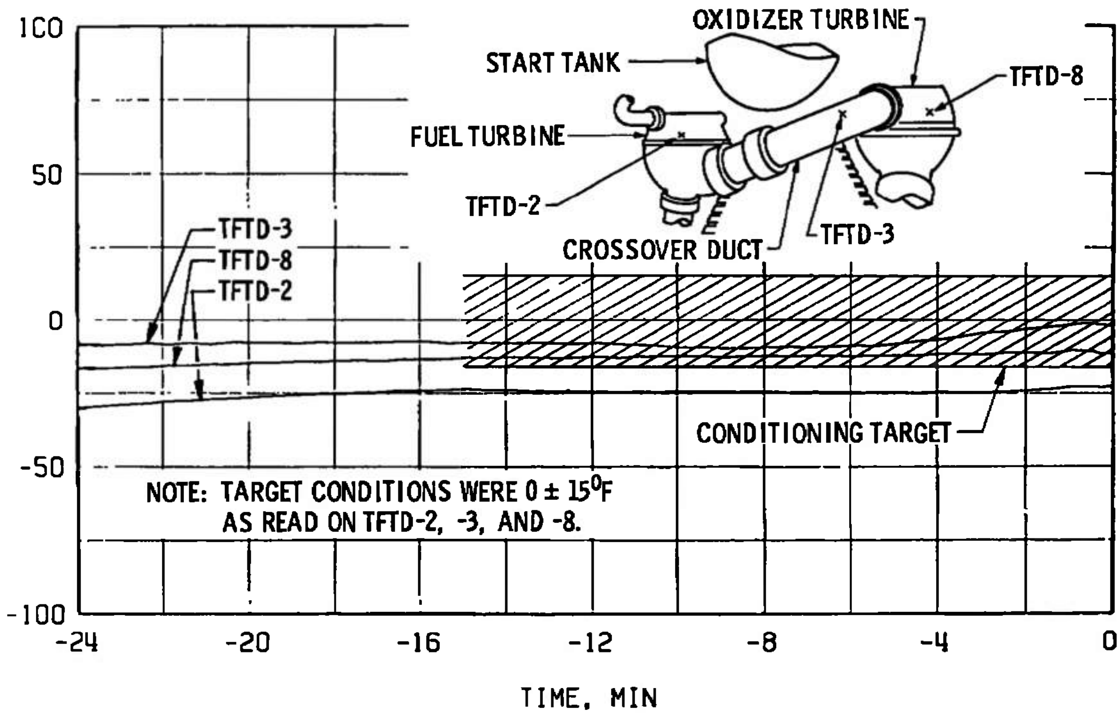
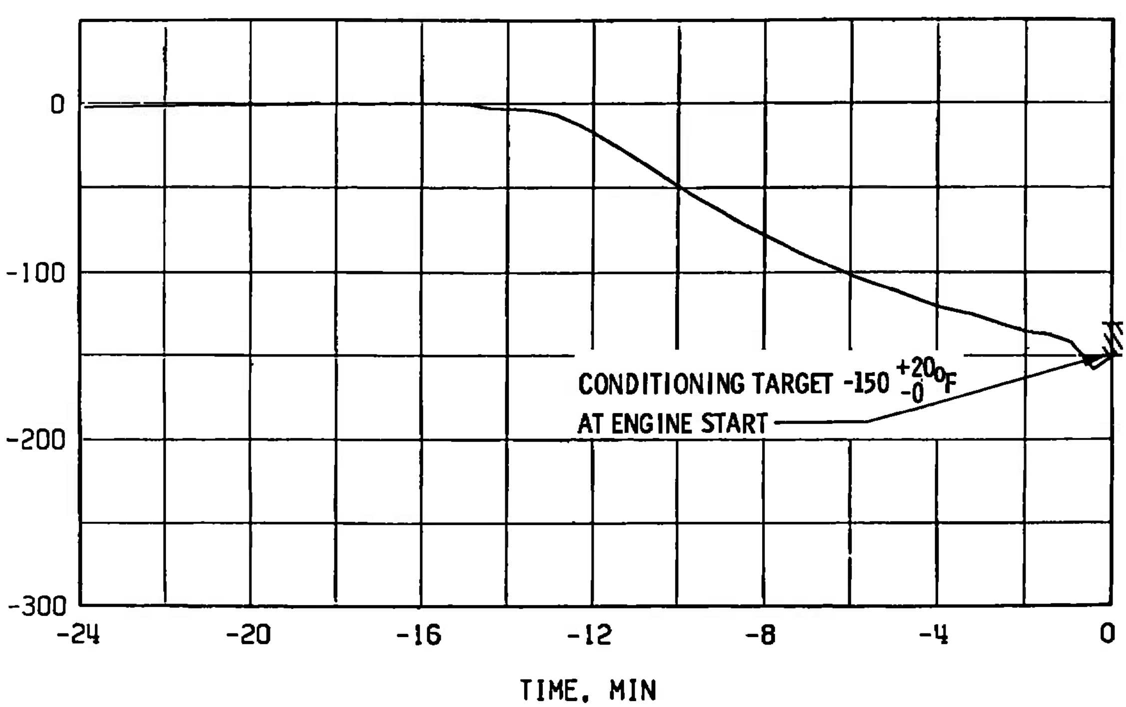


Fig. 24 Engine Ambient and Combustion Chamber Pressure, Test 10D



a. Crossover Duct, TFTD



b. Thrust Chamber Throat, TSC2-19

Fig. 25 Thermal Conditioning History of Engine Components, Test 10D

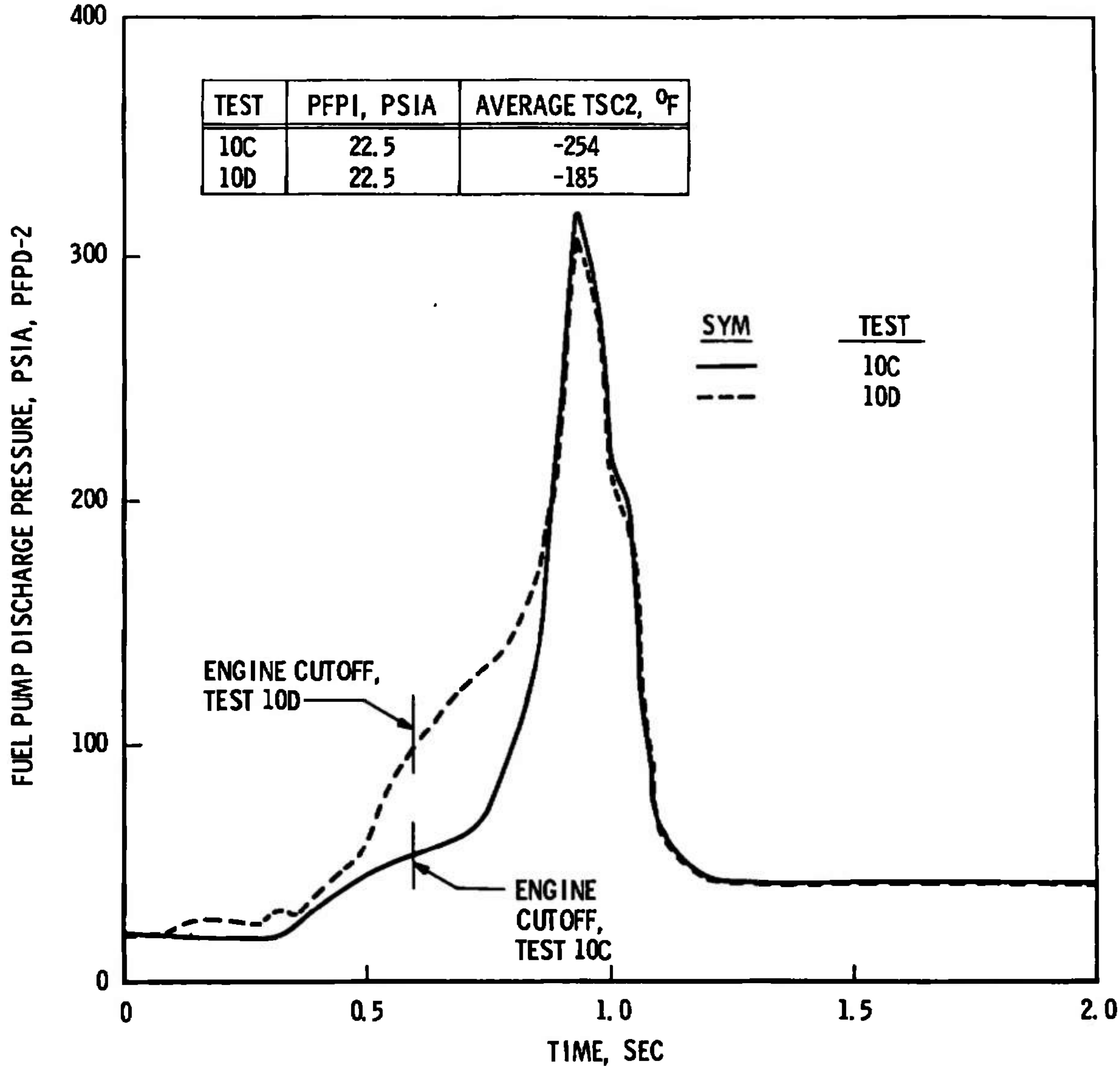


Fig. 26 Comparison of Fuel Pump Discharge Pressure for Tests 10C and 10D

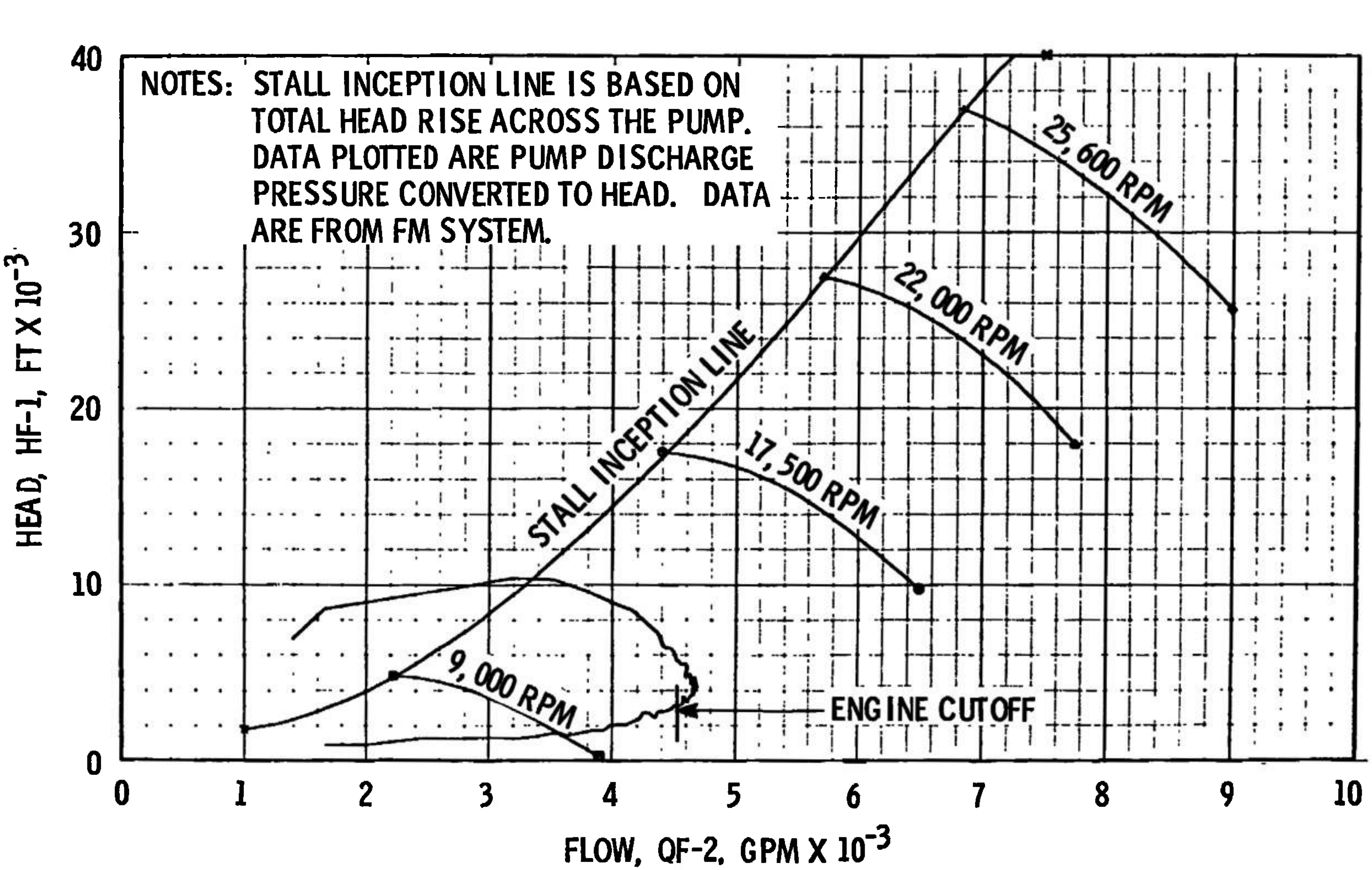


Fig. 27 Fuel Pump Start Transient Performance, Test 10D

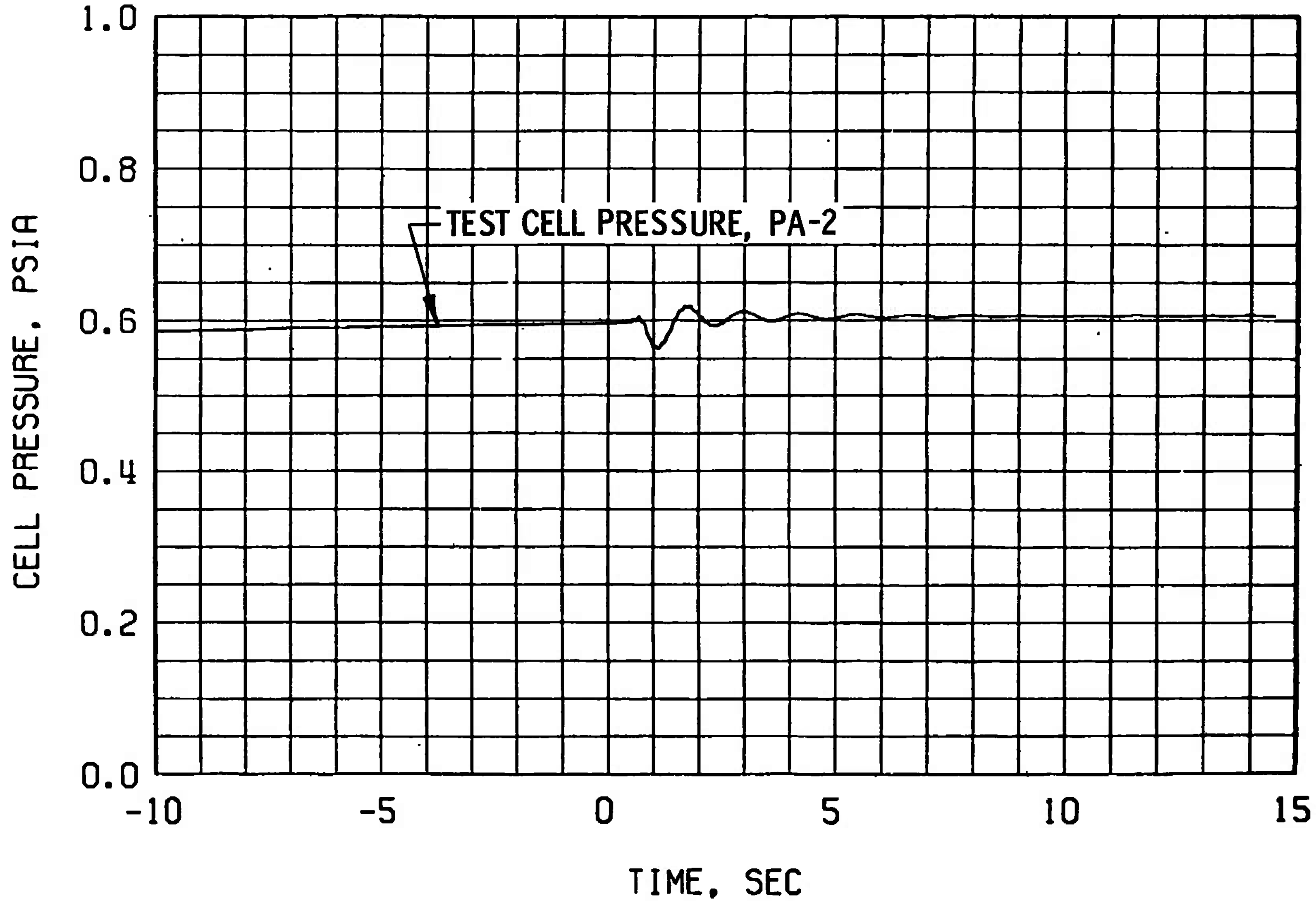
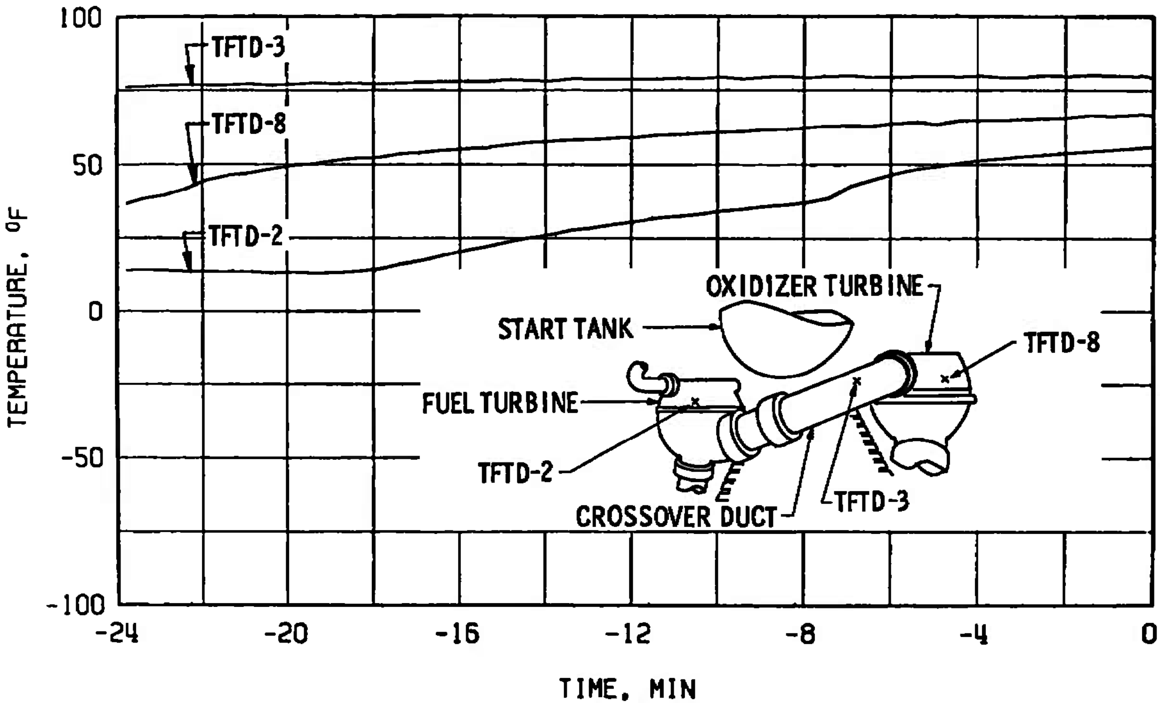
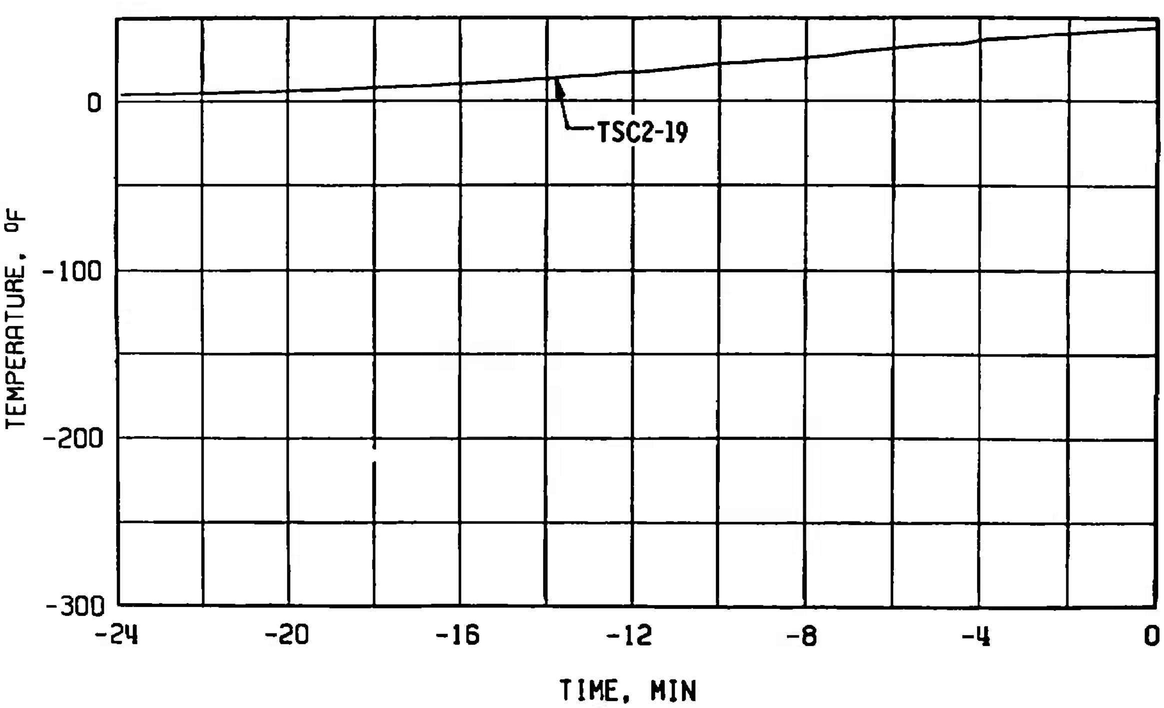


Fig. 28 Engine Ambient Pressure, Test 10E



a. Crossover Duct, TFTD



b. Thrust Chamber Throat, TSC2-19

Fig. 29 Thermal Conditioning History of Engine Components, Test 10E

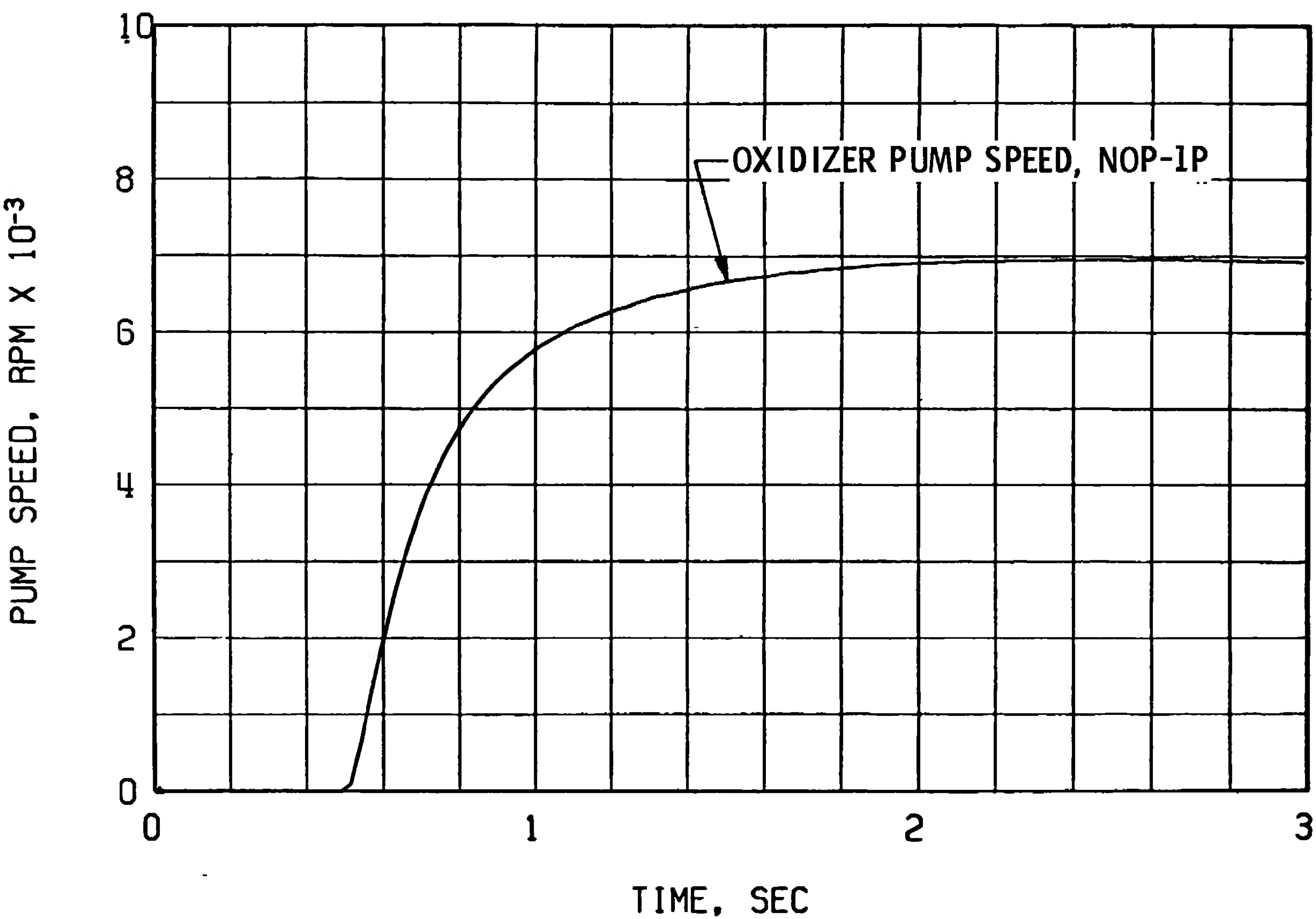


Fig. 30 Engine Transient Operation, Oxidizer Pump Speed, Start and Shutdown, Test 10E

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4076553
Thrust Chamber Injector Assembly	208021-11	4084917
Fuel Turbopump Assembly	459000-181	4062085
Oxidizer Turbopump Assembly	458175-71	6623549
Start Tank	303439	0064
Augmented Spark Igniter	206280-21	3661349
Gas Generator Fuel Injector and Combustor	308360-11	2008734
Pneumatic Control Assembly	558130-41	4092999
Electrical Control Package	502670-11	4081748
Primary Flight Instrumentation Package	703685	4078716
Auxiliary Flight Instrumentation Package	703680	4078718
Main Fuel Valve	409120	4056924
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4079062
Oxidizer Turbine Bypass Valve	409940	4048489
Propellant Utilization Valve	251351-11	4068944
Main-Stage Control Valve	558069	8313568
Ignition Stage Control Valve	558069	8275775
Helium Control Valve	106012000	3793-0
Start Tank Vent and Relief Valve	557828-X2	4046446
Helium Tank Vent Valve	106012000	342277
Fuel Bleed Valve	309034	4077749
Oxidizer Bleed Valve	309029	4077746
Augmented Spark Igniter Oxidizer Valve	308880	4077205
P/A Purge Control Valve	557823	4073021
Start Tank Fill/Refill Valve	558000	4079001
Fuel Flowmeter	251225	4077752
Oxidizer Flowmeter	251216	4074114
Fuel Injector Temperature Transducer	NA5-27441	12401
Restartable Ignition Detect Probe	XEOR915389	211

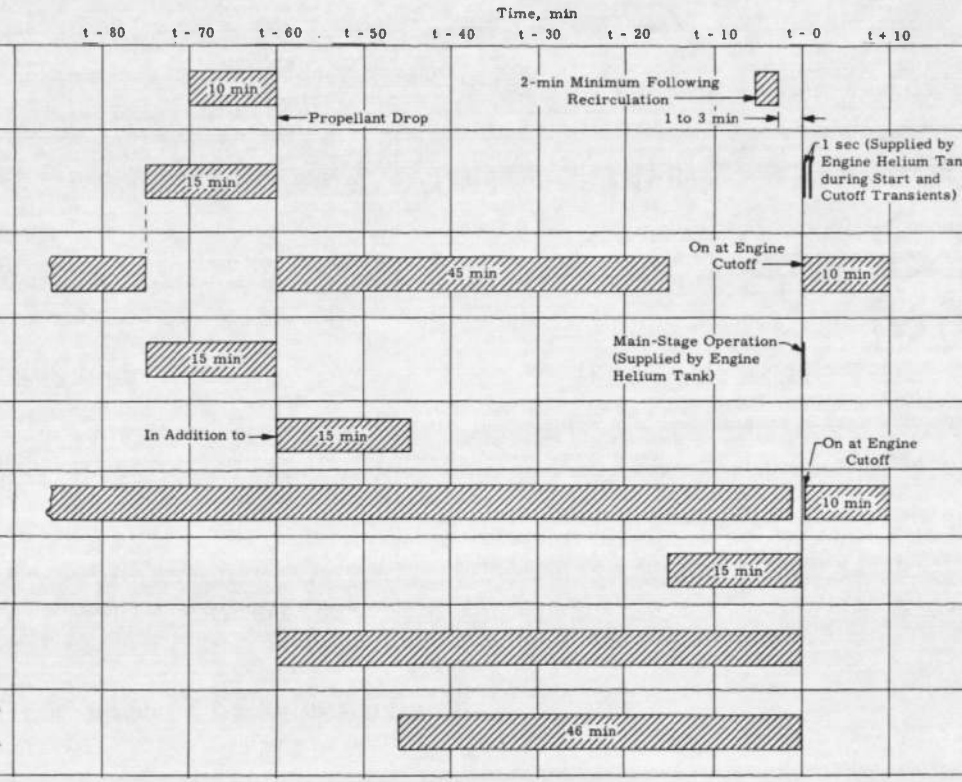
TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Date Effective	Comments
Gas Generator Fuel	RD251-4107	0.480	August 18, 1967	FTP* Replacement
Gas Generator Oxidizer	RD251-4106	0.281	August 18, 1967	FTP Replacement
Oxidizer Turbine Bypass Valve	RD273-8002	1.571	July 31, 1967	RFD† -AEDC 58-67
Main Oxidizer Valve Closing Control	410437	8.65	August 28, 1967	RFD- AEDC 17-1-67
Oxidizer Turbine Exhaust	RD251-9004	10.0	January 18, 1967	Size Verification
Augmented Spark Igniter Oxidizer	406361 None	0.137 0.125	August 10, 1967	RFD- AEDC 62-67

*FTP - Fuel Turbopump
†RFD - Rocketdyne Field Directive

TABLE III
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient 10 - 20 lb_m/min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F



[1]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE IV
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Test Number, J4-1601-10		10A Target	10A Actual	10B Target	10B Actual	10C Target	10C Actual	10D Target	10D Actual	10E Target	10E Actual
Time of Day/Firing Date		1953/Sept 19, 1967		2301/Sept 19, 1967		2400/Sept 19, 1967		0100/ Sept 20, 1967		0221/Sept 20, 1967	
Pressure Altitude at Engine Start, ft		90,000		108,000		107,500		107,000		72,000	
Firing Duration, sec		0.592		0.566		0.590		0.591		---	
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	25^{+0}_{-1}	24.1	25^{+0}_{-1}	24.6	23^{+0}_{-1}	22.5	23^{+0}_{-1}	22.5	---	14.4
	Temperature, °F	-421.7 ± 0.4	-421.6	-421.7 ± 0.4	-422.0	-421.0 ± 0.4	-421.3	-421.0 ± 0.4	-421.4	---	*
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	37.0 ± 1.0	46.3	37.0 ± 1.0	38.4	37.0 ± 1.0	36.9	37.0 ± 1.0	36.3	---	16.0
	Temperature, °F	---	-310.7	---	-311.1	---	-311.2	6	-310.5	---	*
Start Tank Conditions at Engine Start	Pressure, psia	1300 ± 10	1299	1300 ± 10	1306	1300 ± 10	1309	1300 ± 10	1307	1450 ± 10	1452
	Temperature, °F	-300 ± 10	-300	-300 ± 10	-304	-300 ± 10	-306	-300 ± 10	-304	-250 ± 10	-256
Helium Tank Conditions at Engine Start	Pressure, psia	---	2221	---	2410	---	2229	---	2811	---	2219
	Temperature, °F	---	-303	---	-308	---	-309	---	-311	---	-245
Thrust Chamber Temperature Conditions at Engine Start	Throat	-250^{+0}_{-20}	-242	-150^{+20}_{-0}	-144	-250^{+0}_{-20}	-256	-150^{+20}_{-0}	-150	---	44
	Average	-250^{+0}_{-20}	-226	-150^{+20}_{-0}	-170	-250^{+0}_{-20}	-254	-150^{+20}_{-0}	-185	---	56
Crossover Duct Temperature at Engine Start, °F	TFTD-2	0 ± 15	-7	0 ± 15	-24	0 ± 15	-20	0 ± 15	-23	---	55
	TFTD-3	0 ± 15	-6	0 ± 15	-12	0 ± 15	-3	0 ± 15	-2	---	79
	TFTD-6	0 ± 15	-9	0 ± 15	-15	0 ± 15	-10	0 ± 15	-11	---	66
Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F		---	+52	---	±0.5	---	+8	---	-1	---	23
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		---	-72	---	-204	---	-214	---	-215	---	-88
Pneumatic Control Package Temperature at Engine Start, °F		---	+65	---	+17	---	-6	---	-20	---	-27
Fuel Lead Time, sec		1.0	1.019	1.0	1.024	1.0	1.019	1.0	1.019	---	---
Propellant in Engine Time, min		60	60	60	60	60	60	60	60	---	N/A
Propellant Recirculation Time, min		10	15	10	10	10	10	10	10	---	N/A
Prevalve Sequencing Logic		Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	---	N/A
Gas Generator Control Valve Body Temperature at Engine Start, °F		---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0		--- / ---	None / ---	--- / ---	None / ---	--- / ---	None / ---	--- / ---	None / ---	--- / ---	None / ---
Gas Generator Outlet Temperature, °F	Initial Peak	---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
	Overshoot	---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
Main Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)		---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)		---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
Main-Stage Pressure No. 2, sec (Ref. t_0)		---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	N/A	---	N/A	---	N/A	---	N/A	---	N/A
Propellant Utilization Valve Position at Engine Start, deg Engine Start/t_0 + 10 sec		Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	Null / ---	--- / ---	--- / ---

*Out of Thermocouple Range

TABLE V
ENGINE VALVE TIMINGS

Test Number J4-1801-	Start																					
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
10A	0	0.155	0.142	N/A	N/A	N/A	-1.019	0.055	0.064	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10B	0	0.167	0.155	N/A	N/A	N/A	-1.024	0.055	0.069	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10C	0	0.166	0.156	N/A	N/A	N/A	-1.019	0.056	0.071	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10D	0	0.167	0.156	N/A	N/A	N/A	-1.019	0.058	0.070	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10E	0	6	0.072	N/A	N/A	N/A	6	0.097	0.219	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
Final Sequence	0			N/A	N/A	N/A				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5

Test Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
10A	0.592	0.097	0.260	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10B	0.586	0.109	0.303	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10C	0.590	0.110	0.318	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10D	0.591	0.110	0.314	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
10E	6	0.096	0.284	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5
Final Sequence				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5	5	5

1 All valve signal times are referenced to t_0.

2 Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.

3 Final sequence check is conducted without propellants and within 12 hr before testing.

4 Data reduced from oscillogram

5 Run duration was not sufficient to allow oxidizer turbine bypass valve to operate.

6 No start tank discharge control solenoid.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC test J4-1801-10 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 30	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFJT	Fuel Injector Temperature		On/Off	x		x		
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
	Sparks							
RASIS-1	Augmented Spark Igniter Spark No 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0-9000	x		x		
QF-2	Fuel	PFFA	0-9000	x	x	x		
QF-2SD	Fuel Flow Stall Approach Monitor		0-9000	x		x		
QFRP	Fuel Recirculation		0-160	x				
QO-1A	Oxidizer	POF	0-3000	x		x		
QO-2	Oxidizer	POFA	0-3000	x	x	x		
QORP	Oxidizer Recirculation		0-50	x			x	
	Forces		lb_f					
FSP-1	Side Load (Pitch)		±20,000	x		x		
FSY-1	Side Load (Yaw)		±20,000	x		x		
	Heat Flux		$\frac{\text{watts}}{\text{Sr cm}^2}$					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0-7					
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	Pressure		psia					
PA1	Test Cell		0-0.5	x		x		
PA2	Test Cell		0-1.0	x	x			
PA3	Test Cell		0-5.0	x			x	
PC-1P	Thrust Chamber	CG1	0-1000	x			x	
PC-3	Thrust Chamber	CG1A	0-1000	x	x	x		
PCASI-2	Augmented Spark Igniter Chamber	IG1	0-1000	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
PCGG-1P	Gas Generator Chamber Pressure		0-1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0-1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0-1000	x				
PFJ-1A	Main Fuel Injection	CF2	0-1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0-1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0-1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0-1000	x		x		
PFM1	Fuel Jacket Inlet Manifold	CF1	0-2000	x				
PFOI-1A	Fuel Tapoff Orifice Outlet	HF2	0-1000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0-1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0-1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0-1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0-100	x				x
PFPI-2	Fuel Pump Inlet		0-200	x				x
PFPI-3	Fuel Pump Inlet		0-200		x	x		
PFPS-1P	Fuel Pump Interstage	PF6	0-200	x				
PFRPO	Fuel Recirculation Pump Outlet		0-60	x				
PFRPR	Fuel Recirculation Pump Return		0-50	x				
PFST-1P	Fuel Start Tank	TF1	0-1500	x	x			
PFST-2	Fuel Start Tank	TF1	0-1500	x				x
PFUT	Fuel Tank Ullage		0-100	x				
PFVI	Fuel Tank Repressurization Line Nozzle Inlet		0-1000	x				
PFVL	Fuel Tank Repressurization Line Nozzle Throat		0-1000	x				
PHECMO	Pneumatic Control Module Outlet		0-750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0-150	x				
PHES	Helium Supply		0-5000	x				
PHET-1P	Helium Tank	NN1	0-3500	x		x		
PHET-2	Helium Tank	NN1	0-3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0-750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0-50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0-2000	x				
POJ-1A	Main Oxidizer Injection	CO3	0-1000	x				
POJ-2	Main Oxidizer Injection	CO3A	0-1000	x		x		
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0-1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0-1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0-500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0-1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0-1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0-100	x				x
POPI-2	Oxidizer Pump Inlet		0-200	x				x
POPI-3	Oxidizer Pump Inlet		0-100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0-50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0-115	x				
PORPR	Oxidizer Recirculation Pump Return		0-100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0-200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0-100	x				
POUT	Oxidizer Tank Ullage		0-100	x				
POVCC	Main Oxidizer Valve Closing Control		0-500	x	x			
POVI	Oxidizer Tank Repressurization Line Nozzle Inlet		0-1000	x				
POVL	Oxidizer Tank Repressurization Line Nozzle Throat		0-1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0-1000	x				

TABLE III-1 (Continued)

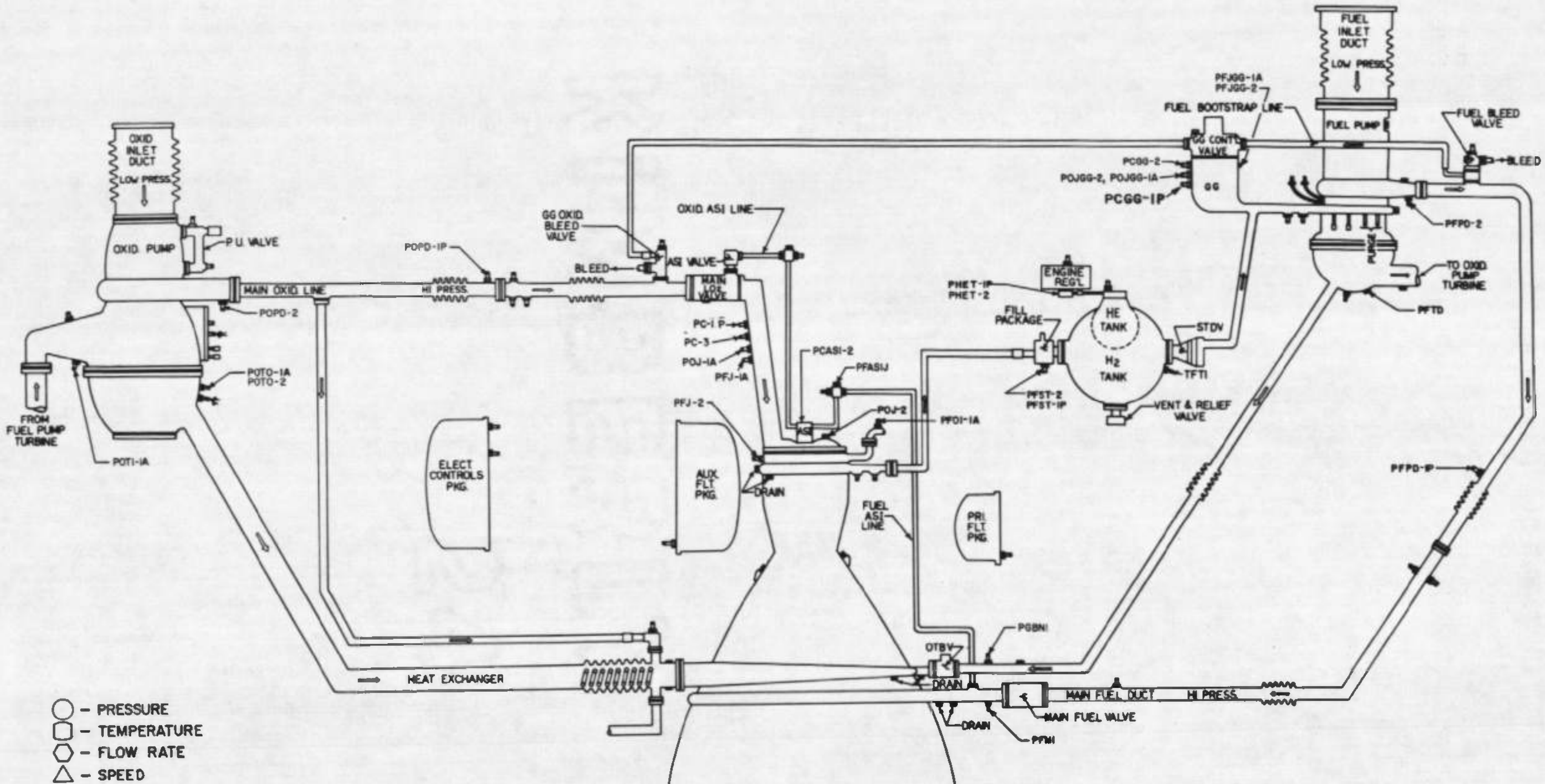
AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PPUVO-1A	Propellant Utilization Valve Valve Outlet	PO9	0-500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0-100	x				
PTCP	Thrust Chamber Purge		0-15	x				
PTPP	Turbopump and Gas Generator Purge		0-250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0-30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0-15,000	x				
NOP-1P	Oxidizer Pump	POV	0-12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0-15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to +800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to +800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBHR-1	Helium Regulator Body (North Side)		-100 to +50	x				
TBHR-2	Helium Regulator Body (South Side)		-100 to -50	x			x	
TBPM	Bypass Manifold		-325 to +200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TCLC	Main Oxidizer Valve Closing Control Line Conditioning		-325 to +200	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x			x	
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x			x	
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to +250	x	x	x		
TFPB-1A	Fuel Pump Bearing		-425 to -325	x				
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to +300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-2	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-1R	Fuel Turbine Discharge Collector		-200 to +900	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-4R	Fuel Turbine Discharge Line		-200 to -900	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x	x	x		
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TMOVC	Main Oxidizer Valve Actuator Conditioning		-325 to +200	x				
TNODP	LO_2 Dome Purge		0 to -300	x				

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOBS-1	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-5	Oxidizer Bootstrap Line		-300 to +250	x				
TOBSCI	Oxidizer Bootstrap Conditioning Inlet		0 to 100	x				
TOBSCO	Oxidizer Bootstrap Conditioning Outlet		0 to 100	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPDS	Oxidizer Pump Discharge Skin		-300 to -100	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Repressurization Line Nozzle Throat		-300 to +100	x				
TPCC	Pre-Chill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TPPC	Pneumatic Package Conditioning		-325 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to -500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to -500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to -500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSECP	Engine Control Package Skin		-50 to +250	x				
TSGGOC	Gas Generator Opening Control Port		-350 to +100	x				
TSOB	Oxidizer Bootstrap Shroud Skin		-200 to +100	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVAL-2	Oxidizer Valve Closing Control Line		-200 to +100	x			x	

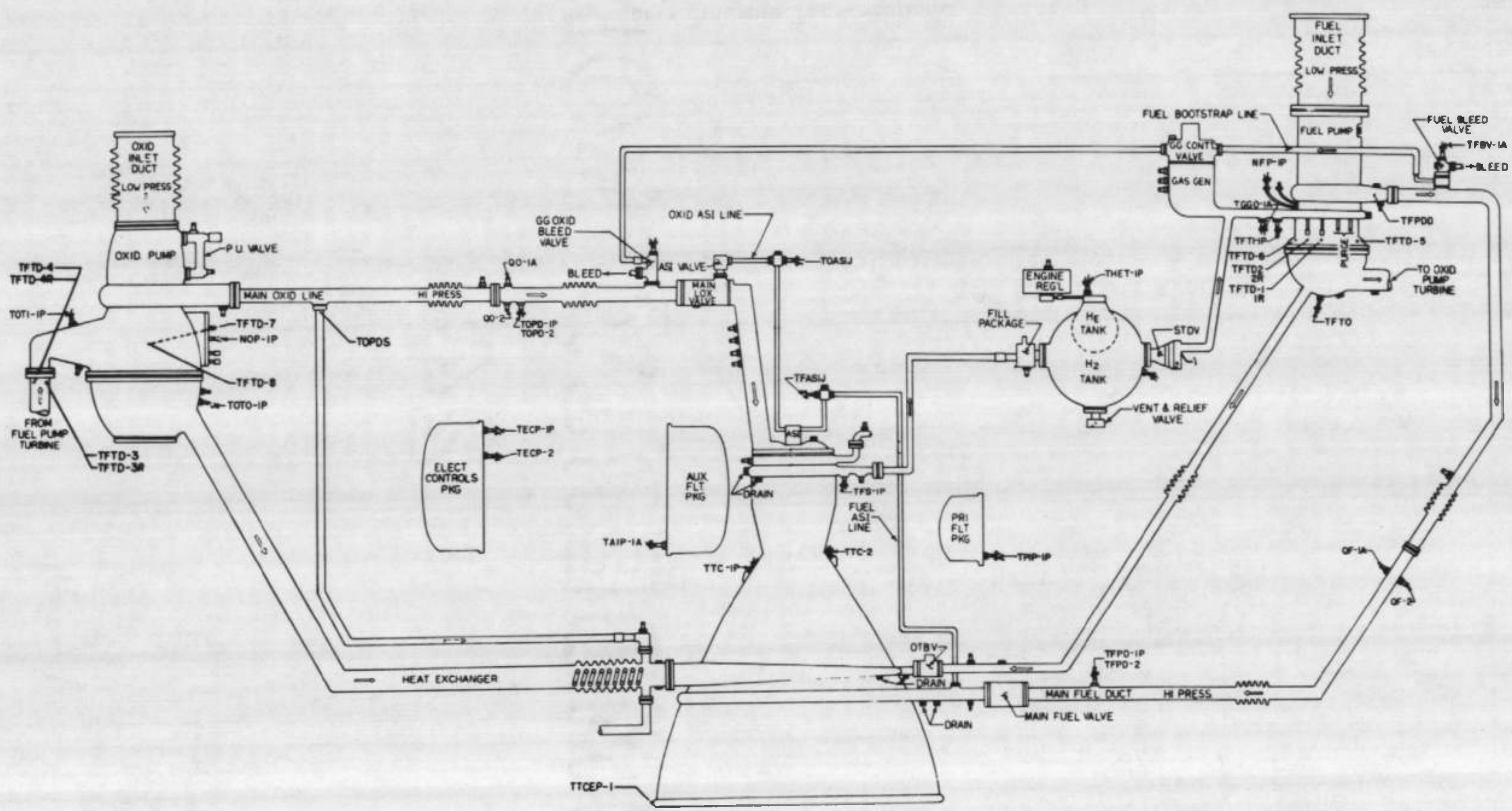
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to -150	x				
TSOVC-2	Oxidizer Valve Actuator Filter Flange		-325 to +150	x				
TSPIP	Primary Instrument Package Skin		-50 to +250	x				
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x				
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x				
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TXOC	Crossover Duct Conditioning		-325 to +200	x				
	Vibrations		g's					
UFPR	Fuel Pump Radial 90 deg		+200		x			
UOPR	Oxidizer Pump Radial 90 deg		+200		x			
UTCD-1	Thrust Chamber Dome		+500		x	x		
UTCD-2	Thrust Chamber Dome		+500		x	x		
UTCD-3	Thrust Chamber Dome		+500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off			x		
	Voltage		Volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				



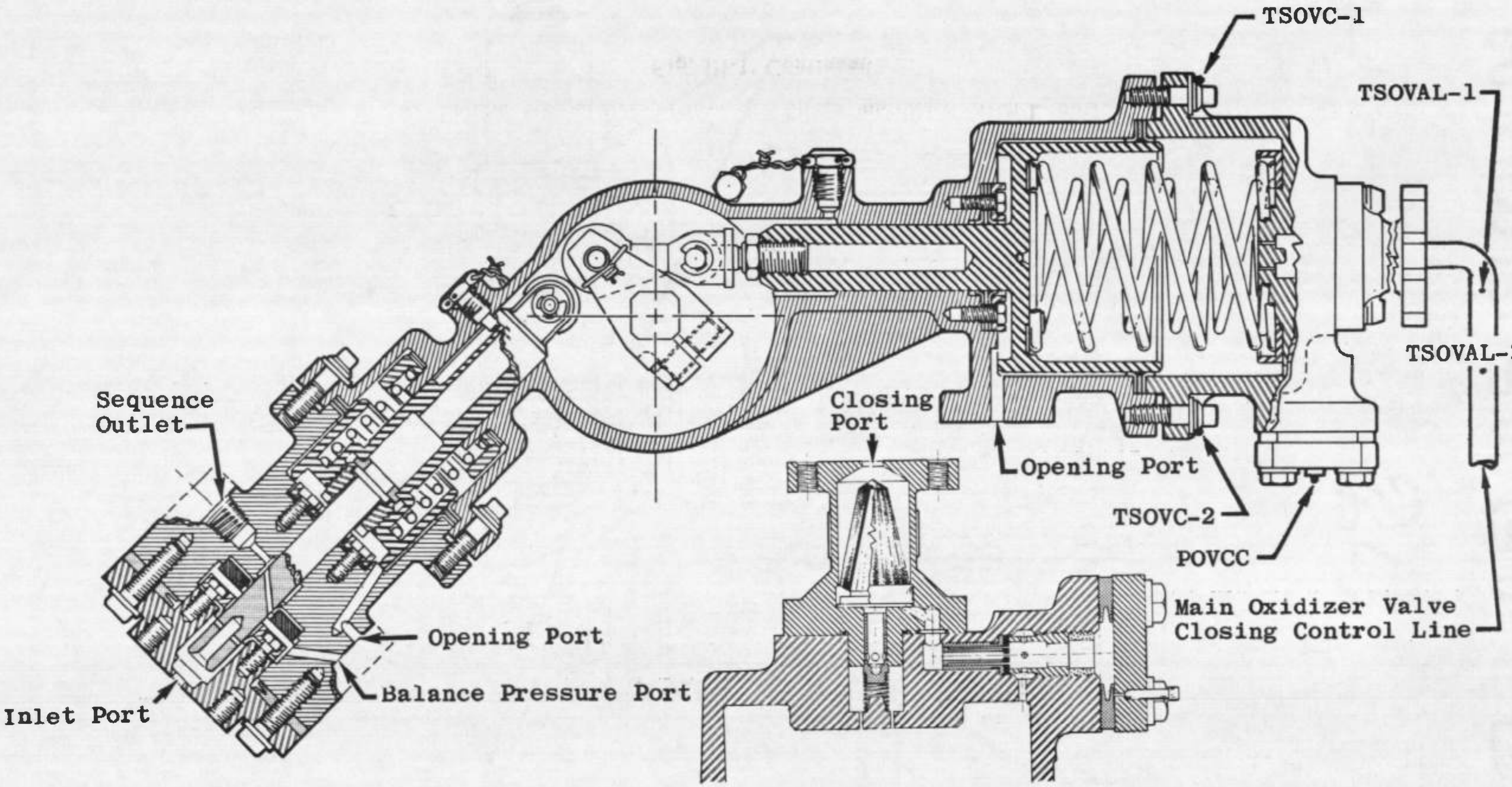
NOTE: INSTRUMENTATION CALLOUTS REFER TO ITEM NUMBERS IN TABLE IV.

a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations

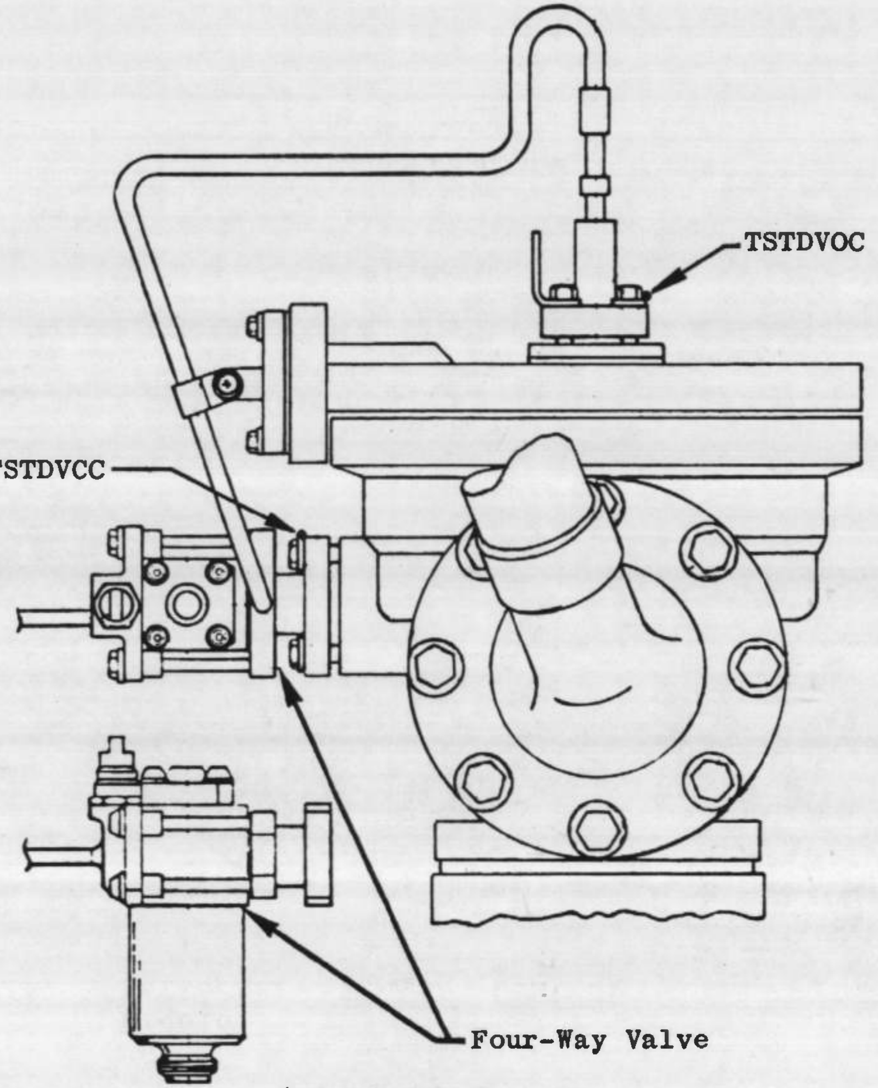


b. Engine Temperature, Flow, and Speed Instrumentation Locations

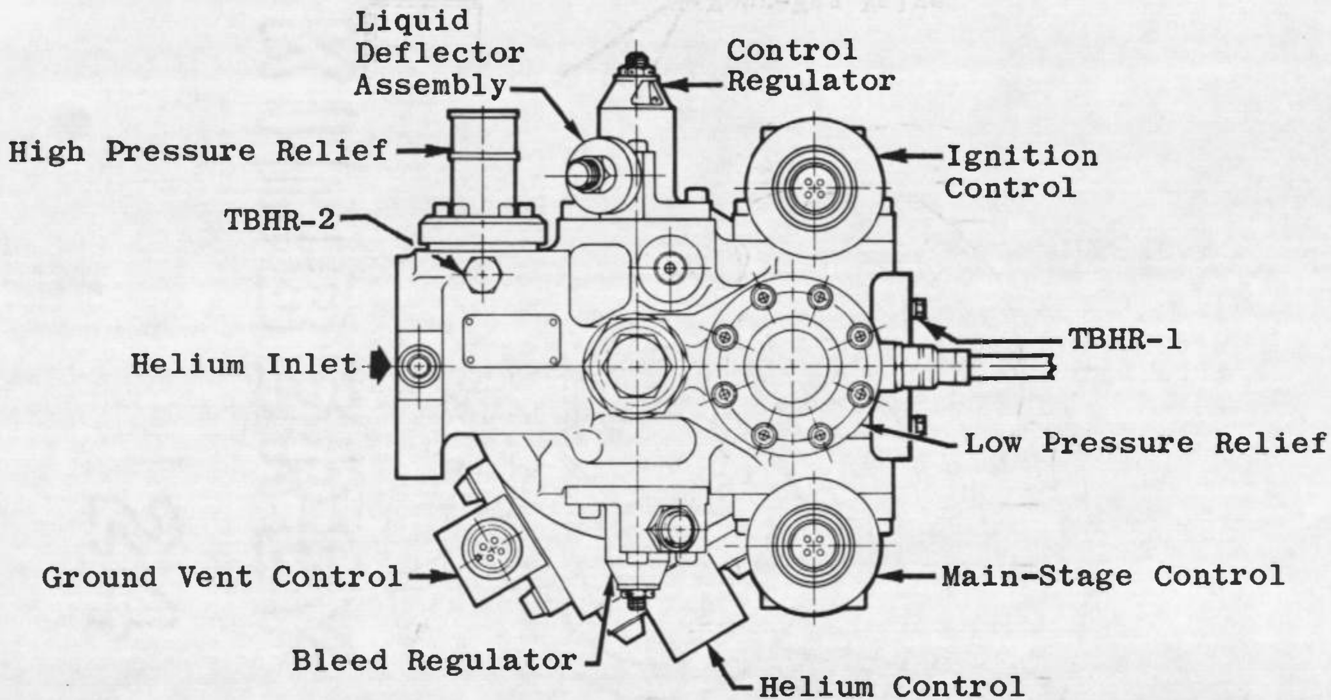
Fig. III-1 Continued



c. Main Oxidizer Valve
Fig. III-1 Continued



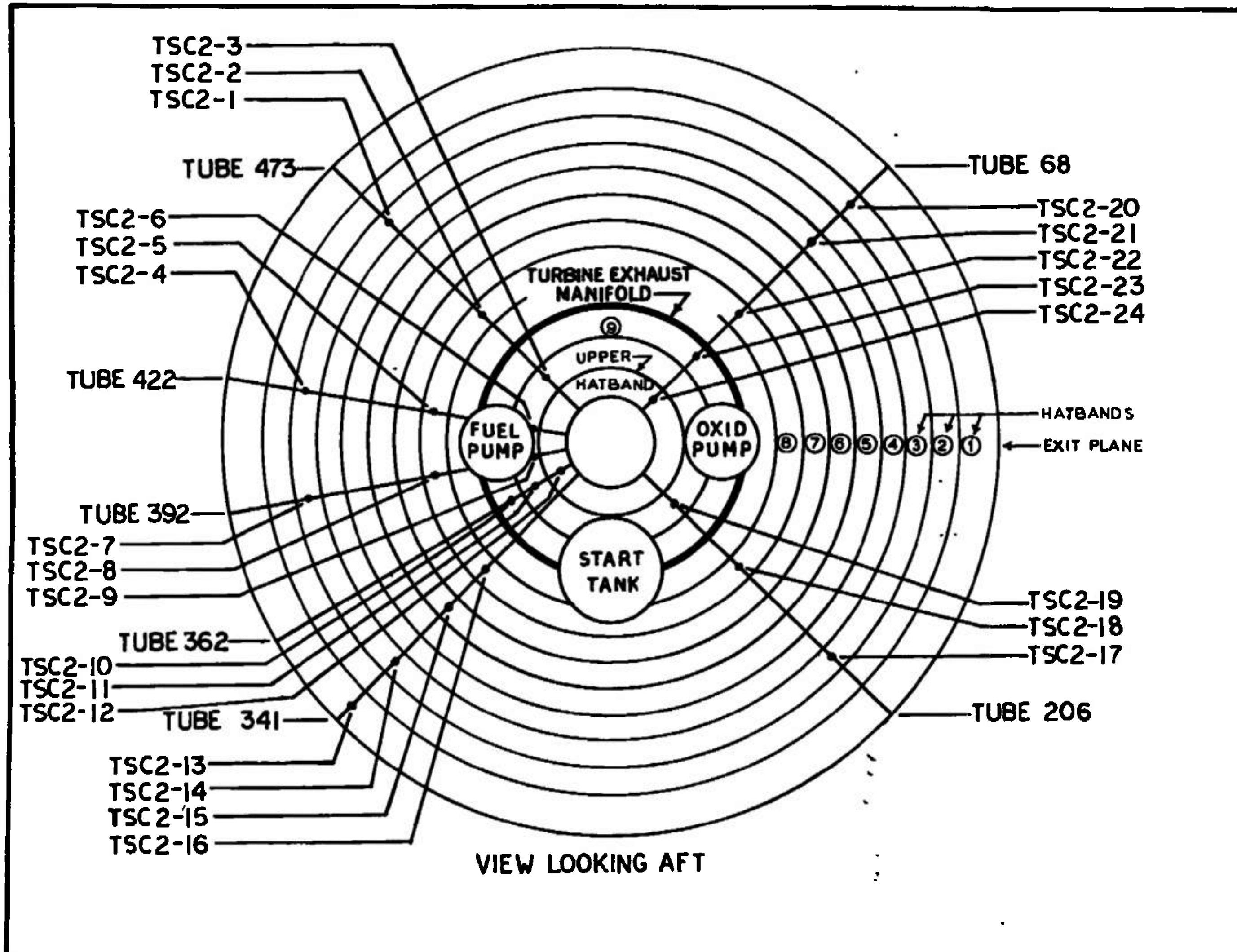
d. Start Tank Discharge Valve
Fig. III-1 Continued



Top View

e. Helium Regulotor

Fig. III-1 Continued



f. Thrust Chamber

Fig. III-1 Concluded

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13. ABSTRACT

Five nonfiring propellant pump performance tests of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. The tests were accomplished during test period J4-1801-10 at pressure altitudes of approximately 100,000 ft to evaluate the effects of low fuel pump inlet pressure on pump operating characteristics (tests 10A through 10D) and to determine the effects of spinup with dry pumps on test 10E. In the first four tests, liquid nitrogen was utilized as the operating fluid in the oxidizer system for safety reasons and to prevent engine firing on any test. Thrust chamber and turbine components were thermally conditioned before each performance test.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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altitude testing						
propellant pump performance						
pressure effects						
dry pump spinup effects						

1. Rocket motors -- J-2

2 " " -- Pump performance

3 Pumps -- Performance

12-3

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